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# THESIS

**ENABLING ENHANCED COMPANY OPERATIONS (ECO): AN ANALYSIS OF TACTICAL COMMUNICATION REQUIREMENTS AND SOLUTIONS FOR A MARINE CORPS COMPANY AND BELOW**

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This research evaluates and describes the optimal communications solution that will enable the Marine Corps Warfighting Lab's (MCWL) concept of Enhanced Company Operations (ECO). Formerly known as Distributed Operations (DO), ECO is a concept that is intended to maximize tactical flexibility through decentralized operations of Marine infantry units in a distributed environment. The ECO environment can be characterized by large geographic areas and unconventional operations that have the potential to pose unique challenges for tactical information system networks.

Proposed current and emerging solutions are designed with proprietary protocols and interfaces as opposed to the development of modularity that enables common standards internetworking. An information systems model, defined by sense, decide, and act nodes, decoupled from the communications network, and the Buddenberg Interoperability Reference Model (BIRM), is employed to evaluate the suitability of current and emerging USMC communications systems for ECO. This thesis posits that the optimal communications solution is one that is designed to ensure interoperability across the internetwork and endpoint devices. The authors conclude that the optimal solution is a tactical mesh network that converges both IP-voice and data at the Layer-3 (ISO Model), and extends the Global Information Grid's (GIG) Convergence Layer to the individual Marine.


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# ABSTRACT

This research evaluates and describes the optimal communications solution that will enable the Marine Corps Warfighting Lab's (MCWL) concept of Enhanced Company Operations (ECO). Formerly known as Distributed Operations (DO), ECO is a concept that is intended to maximize tactical flexibility through decentralized operations of Marine infantry units in a distributed environment. The ECO environment can be characterized by large geographic areas and unconventional operations that have the potential to pose unique challenges for tactical information system networks.

Proposed current and emerging solutions are designed with proprietary protocols and interfaces as opposed to the development of modularity that enables common standards internetworking. An information systems model, defined by sense, decide, and act nodes, decoupled from the communications network, and the Buddenberg Interoperability Reference Model (BIRM), is employed to evaluate the suitability of current and emerging USMC communications systems for ECO. This thesis posits that the optimal communications solution is one that is designed to ensure interoperability across the internetwork and endpoint devices. The authors conclude that the optimal solution is a tactical mesh network that converges both IP-voice and data at the Layer-3 (ISO Model), and extends the Global Information Grid's (GIG) Convergence Layer to the individual Marine.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| 2/7 | 2nd Battalion, 7th Marines |
| ANW2 | Advanced Networking Wideband Waveform |
| AOR | Area of Responsibility |
| BFT | Blue Force Tracker |
| BIRM | Buddenberg’s Interoperability Reference Model |
| BLOS | Beyond Line of Sight |
| C2 | Command and Control |
| C2ID | Command and Control Integration Division |
| C4 | Command, Control, Communications, and Computers |
| CAPSET | Capability Set |
| CAS | Close Air Support |
| CASEVAC | Casualty Evacuation |
| CIO | Chief Information Officer |
| CIRPAS | Center for Interdisciplinary Remotely-Piloted Aircraft Studies |
| CLIC | Company-Level Intelligence Cell |
| COC | Combat Operations Center |
| COI | Conditions of Interest |
| DAMA | Demand Assigned Multiple Access |
| DTCS | Distributed Tactical Communications System |
| DO | Distributed Operations |
| DoD | Department of Defense |
| DOTC2 | Distributed Operations Tactical Command and Control |
| ECO | Enhanced Company Operations |

| | |
|---|---|
| EHF | Extremely High Frequency |
| EPLRS | Enhanced Position Location Reporting System |
| FPS | Frames Per Second |
| GIG | Global Information Grid |
| GPS | Global Positioning System |
| HQMC | Headquarters Marine Corps |
| IEEE | Institute of Electrical and Electronics Engineers |
| IFF | Identification of Friend or Foe |
| IOAG | Infantry Operational Advisory Group |
| IP | Internet Protocol |
| ISO | International Organization for Standardization |
| IISR | Integrated Intra-Squad Radio |
| JTRS | Joint Tactical Radio System |
| Kbps | Kilobits per second |
| LAN | Local Area Network |
| LOE | Limited Objective Experiment |
| MAC | Media Access Control |
| MAGTF | Marine Air-Ground Task Force |
| MCCDC | Marine Corps Combat Development Command |
| MCTSSA | Marine Corps Tactical Systems Support Activity |
| MCWL | Marine Corps Warfighting Lab |
| MEF | Marine Expeditionary Force |
| NCW | Network Centric Warfare |
| NLOS | Non-Line-of-Sight |
| NPS | Naval Postgraduate School |

| | |
|---|---|
| OEF | Operation Enduring Freedom |
| OIF | Operation Iraqi Freedom |
| OTH | Over The Horizon |
| OTM | On The Move |
| PHY | Physical |
| PKI | Public Key Infrastructure |
| PLI | Position Location Information |
| QoS | Quality of Service |
| RF | Radio Frequency |
| SA | Situational Awareness |
| SATCOM | Satellite Communications |
| SHF | Super High Frequency |
| SINCGARS | Single-Channel Ground and Airborne Radio System |
| SIP | Session Initiation Protocol |
| SIPRNET | Secure Internet Protocol Router Network |
| TDMA | Time-Division Multiple Access |
| TNT | Tactical Network Topology |
| UHF | Ultra High Frequency |
| VHF | Very High Frequency |
| VoIP | Voice Over Internet Protocol |
| WAN | Wide Area Network |
| WIMAX | Worldwide Interoperability for Microwave Access |
| WNW | Wideband Networking Waveform |
| WPPL | Wireless Point-to-Point Link |

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Major Jason McHuen: I would like to thank my wife, Vicky, and two daughters, Briana, and Alyssa, for their support and love. This has been a stressful time that demanded a large commitment from all of us. I would especially like to thank Vicky for all of her selfless sacrifices, not only during these last two years, but over the course of a tumultuous and trying 14 years together. She has held our family together, despite being uprooted every few years and left to fend alone for the family during my deployments—I am forever in your debt. I would also like to thank my mother, father, and brothers, for their continued inspirational support.

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# I. INTRODUCTION

> No single activity in war is more important than command and control. Command and control by itself will not drive home a single attack against an enemy force. It will not destroy a single enemy target. It will not affect a single emergency resupply. Yet none of these essential warfighting activities, or any others, would be possible without effective command and control.[1]

## A. BACKGROUND

### 1. Hybrid Challenges and Irregular Warfare

The Marine Corps has been engaged with diverse and adaptive adversaries across a range of threats since its inception. The Marine Corps now faces a radically different enemy, diametrically opposed in its methodology to the adversaries of the twentieth century. Many of the emerging adversaries, predominantly non-state actors, will pursue different objectives and tactics, unbound by geographical regions and political ideologies. The unifying thread tying many future adversaries together is that irregular warfare will characterize these new enemies as they attempt to challenge overwhelming conventional combat superiority. Marines are witnessing hybrid challenges, i.e., the blurring of conventional war, irregular challenges, terrorism, and criminality.[2] Since 2001, the Marine Corps has conducted major combat operations, conducted counterinsurgency operations, and engaged in stability and support operations across the spectrum of conflict in both Afghanistan and Iraq. The adversaries faced in the hybrid challenges of the twenty-first century have transformed the battlefield. The nature of war in the twenty-first century remains unchanged: "a

[1] Marine Corps Doctrinal Publication 6, Command and Control, (Washington, DC: United States Marine Corps, 1996) 35.

[2] Headquarters, United States Marine Corps, Marine Corps Combat Development Command. Concept Paper: Evolving the MAGTF for the 21st Century. March 20, 2009. http://www.quantico.usmc.mil/download.aspx?Path=./Uploads/Files/CDI_Evolving%20the%20MAGTF%2020%20Mar%2009.pdf. (Accessed May 2009).

violent clash of interests between or among organized groups characterized by the use of military force."[3] The significant change faced in today's hybrid challenges lies in the adversaries' motivation; ideologies; and their ability to operate in small, dispersed cellular organizations, lacking clear points of demarcation with the flexibility to blend seamlessly with local populations or swarm on an objective. They often leverage technology to increase their span of control and effectiveness in today's flattened world. Regardless of whether the adversary is a large, conventional state actor or an insurgency with transnational actors, the Marine Corps must have the flexibility to quickly organize and operate with speed and precision, and gain a tactical advantage over the adversary.

### 2. Conventional Doctrine

The Marine Corps has conventionally focused combat development on combined arms maneuver of mechanized forces, primarily at the battalion level and above. Conventional combat doctrine, however, is ineffective in the hybrid battlespace and against enemies engaging in fourth and fifth generation warfare.[4,5]

> As learned by the French in Spain during the Napoleonic Wars, the British in the Boer War, the Turks in North Africa and Arabia during World War I, the Germans in Europe during World War II, the Japanese in the Philippines during World War II, and the U.S. in Vietnam, well organized and highly motivated irregular forces that can refuse combat under unfavorable conditions are exceptionally difficult to defeat with forces that are optimized for traditional combat.[6]

[3] Marine Corps Doctrinal Publication 1-0, Warfighting, (Washington, DC: United States Marine Corps, June 1997) 3.

[4] The term *fourth generation warfare* (4GW) was coined by authors William S. Lind, Keith Nightengale, John F. Schmitt, Joseph W. Sutton and Gary I. Wilson; and has been adopted by many military scholars during the last two decades. 4GW is characterized by a blurring of lines between combat forces returning warfare to a decentralized form. 4GW, although broad in various definition, centers on a non-state enemy.

[5] The term *fifth generation warfare* (5GW) has been discussed by some authors as a product of new technologies, such as nanotechnology; however, a clear definition of 5GW has not been widely accepted or yet recognized.

[6] David S. Alberts and Richard E. Hayes, *Power to the Edge: Command…Control…in the Information Age*," CCRP Publication Series. April 2005. 130.

Concepts such as maneuver warfare and expeditionary maneuver from the sea, however, cannot be abandoned in favor of concentration solely into irregular warfare to counter the asymmetric threats of insurgencies, terrorist organizations and other non-state actors. As emerging generations of warfare evolve, the earlier generations of warfare, with conventional adversaries, will continue to exist. The twenty-first century developments, although, can no longer consider unlimited war, or “overwhelming physical destruction” of an enemy, as the exclusive driver of military capabilities.[7] Following the conclusion of major combat operations in Iraq, as well as military operations in Afghanistan, the Marine Corps has predominantly conducted small-unit missions, i.e., operations at the company level and below, to contend with the hybrid challenges in these theaters. The Commandant of the Marine Corps stated that, “it is incumbent on the Marine Corps combat development process to identify requirements that will lead to training, manning, and equipping Marines for the conduct of expeditionary operations across the spectrum.”[8] It is in the enhancement and development of small-unit operations, down to the individual Marine, that the Marine Corps must focus more effort in capability development, technology infusion and enhanced command and control (C2) to allow small units to effectively operate in this new battlespace.

### 3. Distributed Operations

The Marine Corps has conducted concept exploration and developed warfighting experiments to address asymmetric threats and emerging challenges at the Marine Corps Warfighting Laboratory (MCWL) and other components of the Marine Corps Combat Development Command (MCCDC). Early experimentation in the 1990s led to concept focus of small-unit operations at the squad and platoon level that would lead to the concept exploration of Distributed

[7] “Marine Operating Concept for a Changing Security Environment (MOC), 3d Edition.” (Washington, DC: United States Marine Corps, January 2009) 1.

[8] “A Concept for Enhanced Company Operations,” (Washington, DC: United States Marine Corps, August 2008) 1.

Operations (DO). DO was a two-year program conducted from 2004 through 2006, characterized by decentralization, complexity, multi-dimensionality, and increased capability at the small-unit level. DO was an operating approach focused on the deliberate use of separation and coordinated, interdependent tactical actions with decentralized C2 to enhance the DO unit's advantage over a fluid, asymmetric adversary in an extended and complex battlefield. The concept bedrock is the capacity for coordinated action by dispersed units throughout the battlespace.

Following the conclusion of DO experimentation, a "Tactical Capabilities for Irregular Warfare Conference" was held in June 2007 to identify irregular warfare required capabilities. MCWL assessed the conference findings and began to shift the focus of effort from the squad and platoon-focused DO program to the company level. The follow-on concept development was termed ECO.[9]

Among contributions from the study and exploration of DO experimentation is that small, highly capable units can be dispersed over greater distances, operating much more quickly and efficiently than current doctrine cites. Moreover, empowering junior leaders in small units with the authority to make informed decisions aligned with commander's intent increases speed of command. Further, these rapid self-synchronizing small units can cover greater ground, while finding and engaging even the most fluid and adaptive cellular adversaries. In order to realize the beneficial aspects of a DO implementation, there are three areas that would require significant effort and technology development: communications; logistics; and education and training.[10] Although each of these areas is a critical element to the successful implementation of DO, the first element, communications, is of paramount essence; essential not only to

[9] Vincent J. Goulding, Jr., "Enhanced Company Operations: A Logical Progression to Capability Development." Marine Corps Gazette. Quantico, VA. August 2008.

[10] "Distributed Operations: Communications, Logistics, Education, and Training." Naval Research Advisory Committee Report. Office of the Assistant Secretary of the Navy (Research, Development and Acquisition). Washington, D.C. July 2006.

developing concepts such as DO and ECO, but central to operations at every level across the spectrum of conflict. Accessible and reliable communications are cornerstone to the survivability and lethality of DO and ECO units.

### 4. Enhanced Company Operations

ECO experimentation, as with its predecessor DO, consists of a series of Limited Objective Experiments (LOE). LOEs focus on the operational utility of a technology or the operational utility of an experimental tactic, technique or procedure.[11] LOEs 1 and 2 are the company-level intelligence cell (CLIC) and the company-level operations center, respectively. Additionally, ECO will consist of two more LOEs: LOE 3 and LOE 4. LOE 3 will examine two major objective areas in the context of an irregular enemy: logistics and casualty handling; and, C2. ECO will conclude with a final LOE scheduled for 2010 that focuses on the employment of a reinforced rifle company operating from the sea.[12]

MCWL is scheduled to conduct LOE 3 in the late summer of 2009. It is intended to focus on company-level C2, as well as an examination of distributed logistics. This thesis will focus on the concepts and technology development that enable C2 that will be the focus of LOE 3.

LOE 3 takes the information exchange requirements of an ECO company and examines the efficacy of an experimental network backbone[13] beyond the traditional communications medium of a radio frequency (RF) voice network. The experiment designers at MCWL recognize that establishing a digital network is the foundational bedrock for ECO-as well as all other operations under the

[11] Marine Corps Warfighting Laboratory, "MCWL Analysis Reports," https://www.mcwl.quantico.usmc.mil/analysisrpts.cfm. (Accessed May 2009).

[12] Vincent J. Goulding, Jr., "Enhanced Company Operations: A Logical Progression to Capability Development." Marine Corps Gazette. Quantico, VA. August 2008.

[13] The term "backbone" refers to the transmission line or the part of the command and control system that serves as the long-haul communication link or provides a reach-back capability.

concept of network centric warfare (NCW)[14] and services in the Global Information Grid (GIG). To emulate a fully capable, on the move (OTM), over the horizon (OTH) network, MCWL developed a netted iridium distributed tactical communications system (DTCS).[15] DTCS will provide the communications link between the ECO Marines and the C2 systems employed that will enhance battlespace awareness and link to battlefield sensors and shooters.

ECO is a concept that purports to maximize tactical flexibility through decentralized operations in dispersed, distributed environment. The dispersion of the company can be defined as either: over large geographical areas that don't conform to conventional areas of responsibility (AOR); or, it can be defined as over urban and other environments where proximity of obstacles, concentration of noncombatants and interference create relative isolation, making conventional C2 more difficult, to the point of ineffectiveness. The nature of ECO experimentation aims to provide an additional warfighting capability to address the challenges faced in the hybrid battlespace, particularly at the company level where a broad gap in C2 capability is extant. Tactical commanders at the company level are now responsible for the geography and missions that have traditionally been assigned to a battalion, or higher. In order for a company to effectively operate under the ECO construct, the shortcomings of the current and proposed tactical C2 architecture must be addressed before enhanced and additive capabilities can be realized. Until then, the communications capability will always be a limiting factor.

This thesis will focus on enabling ECO through critical analysis of current and future tactical communication requirements, and will identify the limitations of current and proposed solutions. Current and developing technologies and

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[14] David S. Alberts and Richard E. Hayes, Network Centric Warfare: Developing and Leveraging Information Superiority, CCRP Publication Series. February 2000.

[15] Vincent J. Goulding, Jr., "Enhanced Company Operations: A Logical Progression to Capability Development." Marine Corps Gazette. Quantico, VA. August 2008.

concepts in the commercial sector, that will provide the foundation for a proposed network communication solution with the unique characteristics of an ECO company, will be explored.

### 5. COC Study CAPSET V for MAGTF C2

In October of 2008, the MCCDC published a report titled "Combat Operations Center (COC) Study Capability Set (CAPSET) V for Marine Corps Air-Ground Task Force (MAGTF) C2." This study focused on the C2 needs of small-unit leaders below the battalion level. It argues that, while current doctrine and nodal concepts address the communication requirements and roles of staff support missions at the battalion and above, there is little information that describes the common nodes C2 requirements of small-unit leaders.[16] The study describes the changing nature of small-unit leader requirements:

> Historically, small-unit leaders have relied primarily upon voice radios with minimal data capability to receive the Commander's intent and execute missions. While this method of voice transmission has been adequate in the past, the complexity of the environment we now operate in has changed... ...they must have improved situational awareness (SA), increased bandwidth and improved network services. In essence, they must be smarter and better informed than the enemy.[17]

The study was intended to derive and describe the C2 capability requirements for Marine units below the battalion level. In detail, it describes the operations of small-unit C2 nodes and their C2 capability requirements. It also identifies current and planned material solutions and gaps between those material solutions and capability requirements. The CAPSET V MAGTF C2 study illustrates communication capability requirements very similar, if not almost

[16] Command and Control Integration Division (C2ID),. Combat Operations Center (COC) Study Capability Set (CAPSET) V for Marine Corps Air-Ground Task Force (MAGTF) Command and Control (C2). Doctrinal Study, Marine Corps Combat Development Command (MCCDC), United States Marine Corps, Woodbridge: Computer Sciences Corporation, 2008, ES-1.

[17] Ibid.

identical, to those identified as ECO capability requirements by the Marine Corps Warfighting Lab in October of 2008.[18] The similarities of the organizational level focus can be seen in Figure 1 and Figure 2

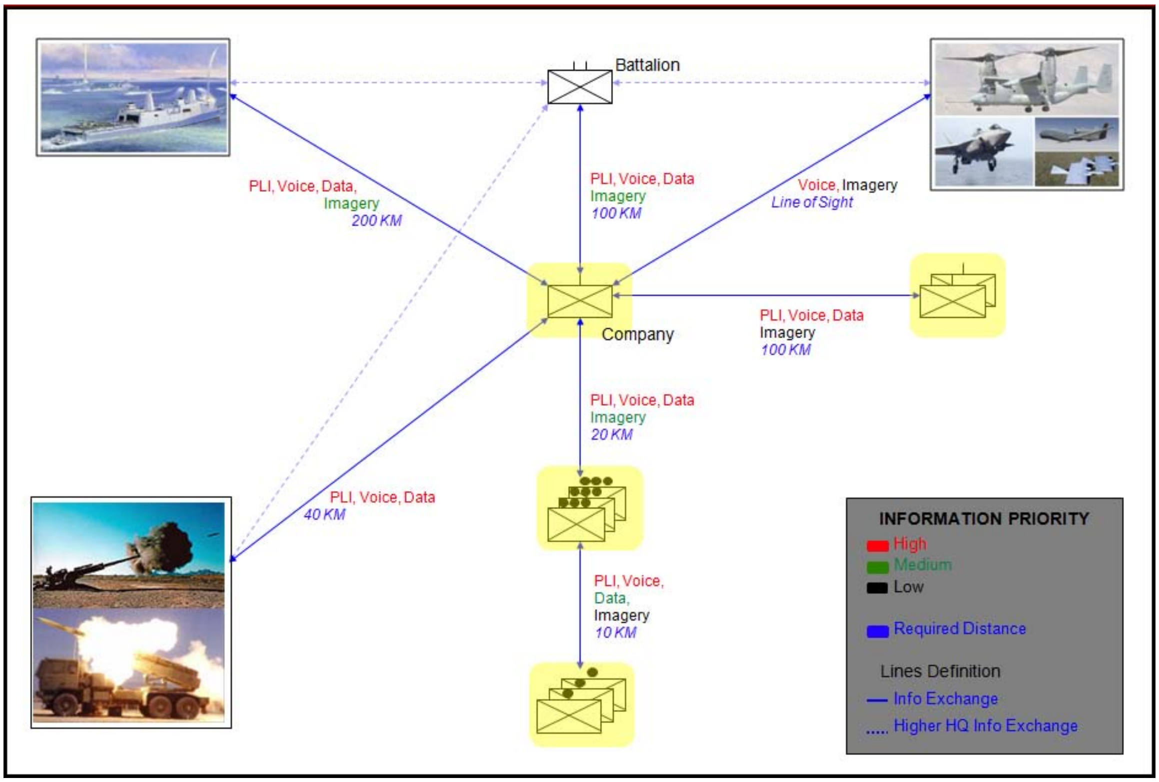


Figure 1 ECO Focus

[18] Marine Corps Warfighting Laboratory. "Enhanced Company Operations" brief presented to the Infantry Operational Advisory Group. October 22, 2008.

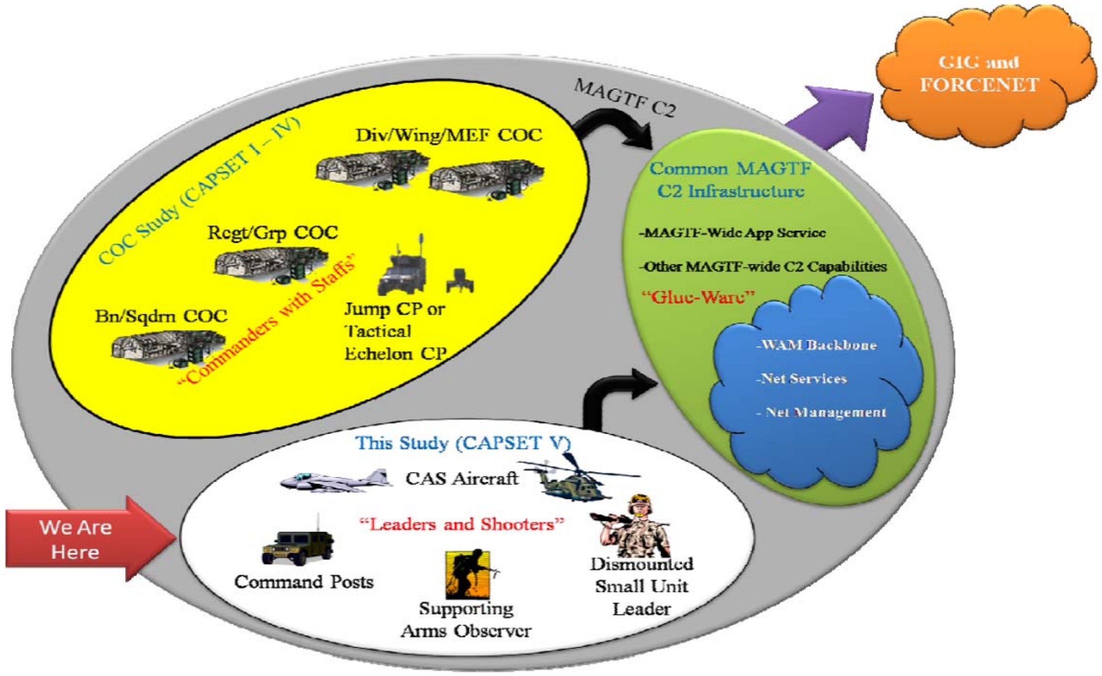


Figure 2 COC Study CAPSET V for MAGTF C2

## B. OPERATIONAL ENVIRONMENT

Marine Corps C2 doctrine states that the C2 system is composed of three basic elements: people, information, and the C2 structure.[19] All three elements play a critical role in the shaping of ECO. The C2 structure is, essentially, an information system. The second and third elements, "information" and the "C2 structure," will form the basis for this thesis. The challenge behind any form of distributed operations or ECO is not in the imagining of new capability, nor merely giving them enhanced tools that allow them to project more combat power with smaller units. To suggest that Marine Corps infantry battalions need greater lethality capability than they currently possess would indicate a misunderstanding of the firepower a battalion can bring to bear on an adversary. The challenge is in maintaining the capability and combat power as smaller units increase their dispersion beyond mutual support. The greater the separation, the higher the

[19] Marine Corps Doctrinal Publication 6, Command and Control, (Washington, DC: United States Marine Corps, October 4, 1996) 3.

diminishment of capability (C2, fires, logistics, human performance, etc.).[20] The C2 structure is the framework for enabling ECO and the information is the critical component that drives the operations that enable ECO.

The departure from traditional philosophies and methodologies of C2 that ECO requires illuminates the shifting characteristics of the battlespace and the information age. Military hierarchies were organized based on their leaders' effective span of control. Empirical wisdom states that a leader can effectively control between three to twelve subordinates in the carrying out of a task or a function. Many subjective factors contribute toward the precise number for the task, e.g., complexity, competency of the subordinates and their leader, and many other human factors. Military hierarchies were established on these same principles and modified as necessary in response to the compelling need for clear and constant communications in the battlespace.[21] The Marine Corps has traditionally organized in operational spans of three: three fire teams to a squad; three squads to a platoon; three platoons to a company, etc. The same basic structures can be traced back to the Civil War when communications relied on voice of command, bugles, couriers, semaphore flags, and the telegraph.[22] As factors are introduced that alter the leader's span of control, i.e., more complexity and friction, the ability to command and control degrades.

ECO represents a shift from a centralized, hierarchical organization of forces (company), to a decentralized element with more independent Marines. This paradigm shift is not new to the Marine Corps. This concept has taken the form of many different names and concepts over the years, but its stark contrast was prominently noted in the late 1990s by then-commandant General Charles Krulak. Krulak illustrated the incredible mounting instability and global disorder that sent Marines into action around the world.

[20] Interview with Lieutenant Colonel Christopher Carolan, Head, Field Testing Branch, Experiment Division, Marine Corps Warfighting Laboratory, Quantico, VA. November 2008.

[21] Martin van Creveld, *Command in War*. Cambridge, MA: Harvard University Press. 1985.

[22] David S. Alberts and Richard E. Hayes, *Power to the Edge: Command Control in the Information Age*," CCRP Publication Series. April 2005. 43.

> In far-flung places like Kenya, Indonesia, and Albania, they have stood face-to-face with the perplexing and hostile challenges of the chaotic post Cold War world for which the "rules" have not yet been written. The three block war is not simply a fanciful metaphor for future conflicts-it is a reality.[23]

The “Three Block War” concept was a nascent insight that would forge the Corps’ emerging challenges amidst the future battlespace’s complexities. It was an early stimulus to the senior leaders that traditional warfighting doctrine will not translate well in the changing nature of future global conflicts. Krulak’s “strategic corporal” was the de facto model of the challenges inherently faced by the small-unit leader. Whether the term du jour is three block war, hybrid challenges, or fourth generation warfare, greater demands are being placed on decision makers at all levels.

There are two basic uses for information: create SA as the basis for a decision; and, for directing and coordinating actions in the execution of the decision; both of which are rarely mutually exclusive in practice.[24] The significance of this is an integral component to determining success for decision makers in the ECO construct. The strategic corporal is indicative of the enhanced education and training sought for Marines operating in ECO companies.[25] Contrasted with Napoleon’s Corporal,[26] the strategic corporal will be required to make decisions with far reaching implications and, often times, in the absence of clear, detailed guidance on handling many flashpoint issues. The

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[23] Charles C. Krulak, “The Strategic Corporal: Leadership in the Three Block War.” Marines Magazine, 28, No. 1. January 1999. 32.

[24] Marine Corps Doctrinal Publication 6, Command and Control, (Washington, DC: United States Marine Corps, October 4, 1996) 49.

[25] The composition and employment of an ECO company is conceptual and has not been clearly defined. In one sense, the ECO company would be a company that has additive skill sets that the typical Marine infantry company lacks, or it could be the construct that successive infantry companies are modeled.

[26] Napoleon’s corporal was a member of Napoleon’s army used to ensure that orders issued by Napoleon were clear and understandable by even the lowest of intellects before being dispatched to Napoleon’s generals.

strategic corporal, who could well be a lance corporal or a even a private in an ECO construct, will need clear commander's intent and accurate SA from which to invoke his own judgment and base his decisions.

Currently, the Marine Corps, along with other joint and coalition services, are deploying units into Afghanistan tasked with military and peacekeeping operations. Many of these units are operating more independently and over greater dispersed and distributed environments. The 2nd Battalion, 7th Marines (2/7), based at the Marine Corps Air-Ground Combat Center in Twentynine Palms, California, deployed to Afghanistan from April 2008 to November 2008. Assigned to the Security Transition Command-Afghanistan, and later to the Special Purpose Marine Air—Ground Task Force—Afghanistan, the 2/7 conducted full-spectrum counterinsurgency operations from locations in Northern Helmand and Eastern Farah Provinces.[27] The 2/7 conducted operations over 10,000 square miles.[28] Frontages like these are being carved more often for smaller sized units contrasting with traditional areas of responsibility.

### 1. Network Centric Warfare

The term NCW[29] describes a theory for warfare, encompassing varying explicit definitions and interpretations, might be described simply as developing and leveraging information superiority. Similar to other transformational warfare theories such as Revolution in Military Affairs, NCW is a concept that illustrates the exponentially increased value of shared awareness and collaboration on the battlefield through the networking of these elements. Alberts and Hayes[30]

[27] First Marine Expeditionary Force, "History of the 2nd Battalion, 7th Marine Regiment." http://www.i-mef.usmc.mil/div/7mar/2bn/history.asp (Accessed May 2009).

[28] Dan Lamothe, "2/7 to Complete Return from Afghanistan." Marine Corps Times. December 7, 2008. http://www.marinecorpstimes.com/news/2008/12/marine_afghanistanreturn_120308w/ (Accessed May 2009).

[29] David S. Alberts and Richard E. Hayes, *Power to the Edge: Command…Control…in the Information Age*," CCRP Publication Series. April 2005.

[30] David S. Alberts and Richard E. Hayes, *Power to the Edge: Command…Control…in the Information Age*," CCRP Publication Series. April 2005.

describe the evolution of information exchange and the mechanisms that have been designed to value, store, share, and access information. They discuss the requirements, advantages, and disadvantages of various information exchange technologies. They begin with the telephone information exchange as seen in Figure 3.

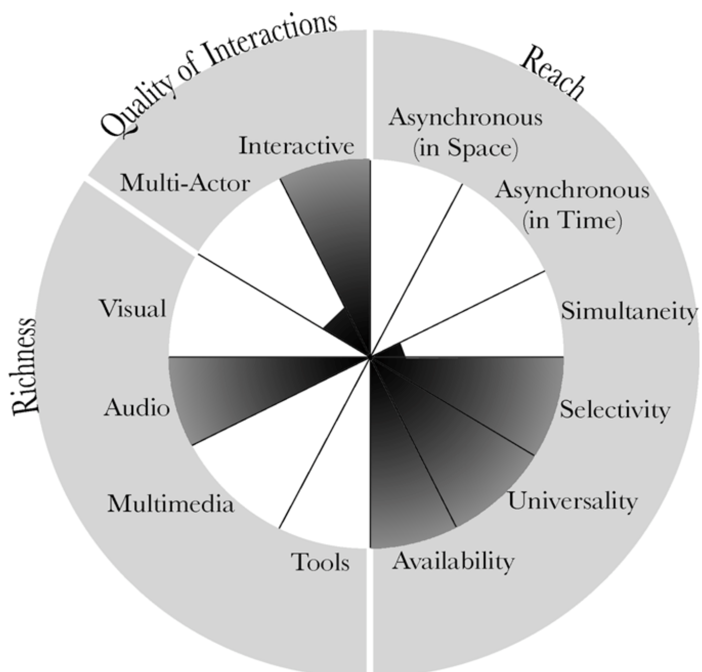


Figure 3 Capabilities of Telephone Information Exchange (From Alberts, 2005)

Information could be effortlessly, but not efficiently, exchanged; however, it relied on various requirements of understanding the value of the information, who needed the information and how to contact them synchronously to exchange the information (voicemail is not an element of their discussion). Although an inefficient system of exchanging information, it was sufficient for short, point-to-point exchanges when the sender, or transmitter, knew how and when to contact the listener, or receiver.

Broadcast capabilities were used in the Department of Defense (DoD) in the 1970s to push, or broadcast, information using either a point-to-point or multicast capability.[31]

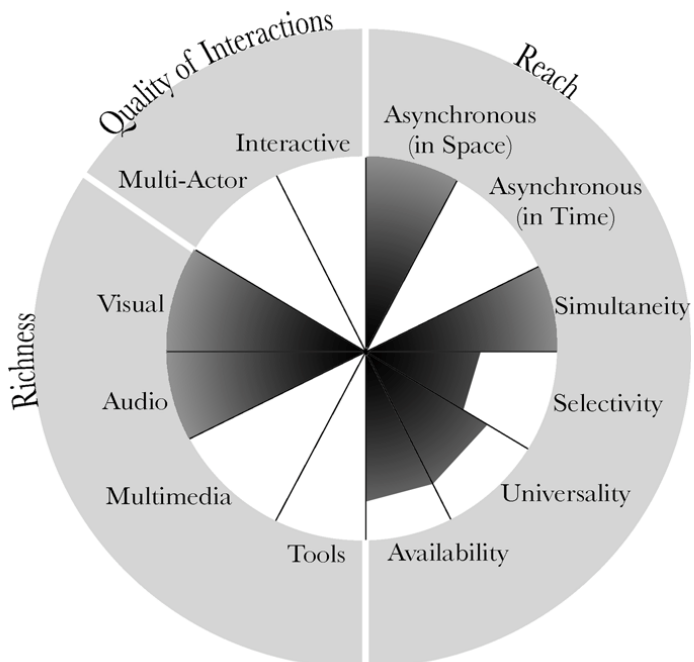


Figure 4 Capabilities of Broadcast Information Exchange (From Alberts, 2005)

The enhanced advantage of broadcast information enables the sender to reach a broad set of listeners simultaneously, introducing video and eliminating the need to know a receiver's "identity." Alberts and Hayes point out that the critical fault in broadcast capability lies in its temporal constraint, i.e., information exchanged required all interested listeners to be present during the transmission. Information was not preserved for later listeners. The information could be re-broadcasted, but doing so would decrease communication efficiency and was still vulnerable to missing interested listeners that were temporally disjointed.

[31] David S. Alberts and Richard E. Hayes, *Power to the Edge: Command Control in the Information Age*," CCRP Publication Series. April 2005. 78.

Combining telephone and broadcast capabilities, they argued, further increased information dissemination capabilities but remained inadequate for warfighting communication requirements.

Alberts and Hayes postulated that warfighter information systems needed a fully networked collaborative environment.[32] Figure 5 illustrates the richness and consummation of the idealized warfighter information system replete with the vital information exchange capability.

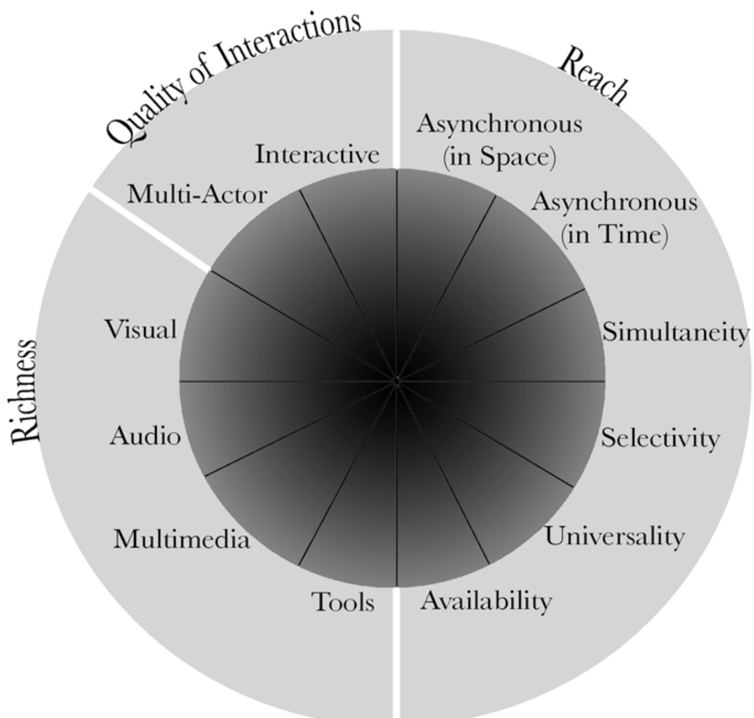


Figure 5 Capabilities of Networked Collaborative Environment (From Alberts, 2005)

The fully networked collaborative environment represents the next stage in evolution. It leaps beyond today's primary tactical communication means of single-channel, push-to-talk radio frequency radios to a fully integrated network that delivers voice, data, availability, accessibility, and is asynchronous in time

[32] David S. Alberts and Richard E. Hayes, *Power to the Edge: Command…Control…in the Information Age*," CCRP Publication Series. April 2005. 81.

and space. Alberts and Hayes point out the myriad challenges in the synthesizing of the information in ensuring that the information is filtered for the ones that need it. Merely having access to information is not the objective. The Internet readily provides more information than users of the World Wide Web can process. The desired network will provide the right information to the right person at the right time. The fully networked collaborative environment would, however, use systems to connect listeners to senders. The challenge is that it may not include all of the listeners and may include some listeners that do not need to be listening and thus clouding their information synthesizer. Combat information systems illustrate this weakness. Many of today's C2 and combat information systems include sensors that link information to target listeners, e.g., position location information (PLI), video, target identification, autonomous logistics, etc. The inherent weakness in these systems is the availability of the information to those that need it; or, at a minimum, additional information exchange requirements to gain access to the information. Many C2 and combat systems use point-to-point pathways that limit access to specific system equipment that can interface with the combat system. Many of these systems have resulted in stove-piped, niche capabilities that are available to a select number of users. The fully networked collaborative environment would be able to share this information across the warfighter network and be accessible to the warfighters that need it.

## C. STATEMENT OF PROBLEM

—Potential enemies encountered in ECO are expected to be unconventional (continuingly modifying current and historically-successful tactics and techniques), and they will strive to attack dispersed Marine units using asymmetric methods. Small-unit leaders will be relied upon to counter this threat. To do so, they must have improved SA, increased bandwidth and improved network services.

- Current and proposed immature communication technologies exist that can be adopted to enhance warfighting capability in the transformed battlefield. However, a requirements statement does not exist that will fuse these technologies in a solution that will enable ECO.
- Current technologies are not designed to the requirements of highly mobile, dynamic, and resource constrained environments of current battlefields.
- Proposed current and emerging solutions are designed with proprietary protocols and interfaces as opposed to development of modularity that enables common standards internetworking.

## D. RESEARCH QUESTIONS

- What is the appropriate framework for evaluating network communications solutions?
- What are the Marine Corps' current and emerging network communications solutions that will enable ECO?
- What is the optimal communications solution that will enable ECO for concept development at MCWL?

## E. METHODOLOGY

1. Research USMC ECO publications, articles, and related material.
2. Conduct site visits to:
    a. MCWL, Quantico, VA
    b. MCCDC, Quantico, VA.
    c. Office of Naval Research (Code 353), Arlington, VA
3. Interview key personnel and conduct limited survey to identify areas of concern regarding the C2 of an ECO unit.
4. Research RF to IP technologies, related reference material and industry experts. Additionally, read relevant and recent Naval Postgraduate School (NPS) thesis research related to C2 systems and ECO.

5. Research interoperability standards in defining communication architecture requirements.

6. Perform laboratory and field tests to evaluate proof of concepts.

## F. ORGANIZATION OF THESIS

This thesis is organized as follows:

**Chapter I** discusses the problem and provides background information into the changing battlespace and the hybrid challenges inherent to today's conflicts. It provides the foundation for why the ECO concept is so critical to shifting Marine Corps operations and how they are departing from current doctrine. Additionally, it states the reason for conducting this research and provides a contextual framework for the reader.

**Chapter II** discusses the importance of defining the taxonomy of the information systems model as applied to the evaluation of a communications system.

**Chapter III** discusses and defines the network requirements used in the evaluation of a communications system.

**Chapter IV** defines the endpoint device requirements used in the evaluation of a communications system.

**Chapter V** is a brief summary of both the network and endpoint device requirements.

**Chapter VI** describes the operational capability requirements for small units as identified by MCWL and the C2ID, MCCDC for ECO and CAPSET V users.

**Chapter VII** evaluates the current and emerging DoD tactical communications systems.

**Chapter VIII** provides an assessment of the communications systems as evaluated against the information systems requirements and attempts to answer the primary research question.

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# II. INFORMATION SYSTEMS MODEL

## A. SEPARATE THE COMPONENTS

In order to achieve the ideal information system, it must be broken down into its conceptual components. The application and data required to conduct, for example, the surveillance of a target in a distributed environment are not relevant to the communications network. The capability to send real time streaming video from a Marine back to a CLIC some distance away is really the functionality of an endpoint device. In this scenario, it would be a networked video camera, but the video camera does not “care” what network it is using or how it gets the streaming video to its intended recipient. The only required capability of the video camera is that it can somehow package the video so that the stream can be passed over a network.

The DoD chronically makes the mistake of developing stovepipe information systems that fail to modularize or decouple the sense, decide, and act nodes and their information from the communications network. A classic and very USMC-relevant example of this phenomenon is the Blue Force Tracker (BFT). The BFT is a closed stovepipe system that is not networkable and thus cannot share information with other networks. The BFT is the primary PLI system for tactical forces that provides a common operating picture at the tactical level. In order to benefit from the information provided by the BFT, a unit must have a BFT device, which incorporates a Global Positioning Satellite (GPS) and satellite radio that cannot be separated from the processing and display part of the system. The sense functionality of the information system is not an endpoint device that can be decoupled from the communications network.[33]

[33] Capt Glen Henton, Deployed Support Team Trip Report OIF, MCTSSA, USMC, 2008.

In order to analyze the requirements of the information system that could enable and support ECO, it is necessary to single out the communications network and its architecture. The endpoint devices on any tactical network must be decoupled from the communication network which connects them. That is to say, any network device, its applications, and the data that is generated or received must be separate and independent of the communications network. If the functional activities, or endpoint devices, are decoupled from the underlying communications network, then the utility of the communications network is infinite and only limited by the different types of endpoint devices that can be attached to the network.

## B. COMMUNICATIONS-SENSE, DECIDE, AND ACT

According to Professor Rex Buddenberg, "information systems contain sense, decide, and act functions, connected together with communications."[34] In this thesis, the "communications" will be synonymous with a communications network. A communications network can be a small tactical single-channel radio network or a global enterprise network comprised of numerous types of architectures, such as the GIG.[35] Buddenberg uses the analogy of a person as an information system. The eyes are the sensors; the brain provides the functionality of "deciding," and then sends signals to the arms and legs to "act." The body's nervous system, or the communications network, ties all of these functions together.

Buddenberg points out that the sense, decide, and act functionality is provided by endpoint systems on a communications network. This analogy can be applied to any tactical weapons platform such as a tank or an individual Marine. For example, a Marine might have a thermal scope (sensor) on his rifle providing imagery to his brain that evaluates a target (decides) and then

[34] Rex Buddenburg, Information Systems Interoperability. 2009.

[35] John G. Grimes, *Department of Defense Global Information Grid Architectural Vision.* DoD CIO Vision Report, Assistant Secretary of Defense Networks & Information Integration-Chief Information Officer, Department of Defense, Washington: DoD CIO, 2007.

prosecutes the target with his rifle (acts). The analogy can be further expanded to illustrate the potential capability of an infantry company conducting ECO. A man-packed aerial reconnaissance drone might be the sensor that is providing imagery a block away from a squad of Marines that decides to act on or engage a target by requesting indirect fire support from the company's mortar section. Conceptually, there can be multiple sense endpoint devices which can pass information to multiple decide or act endpoint devices.

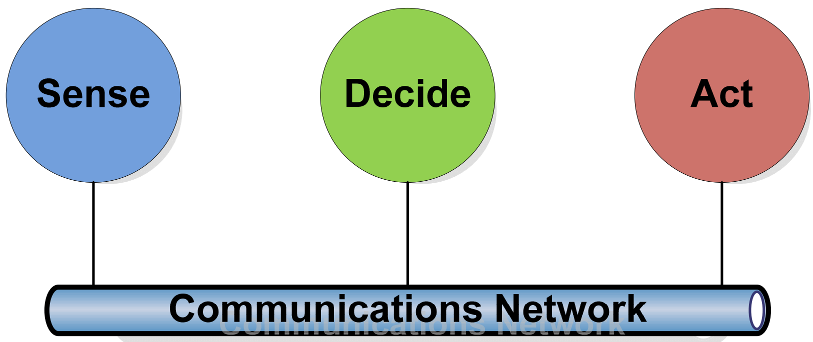


Figure 6 Information Systems Model

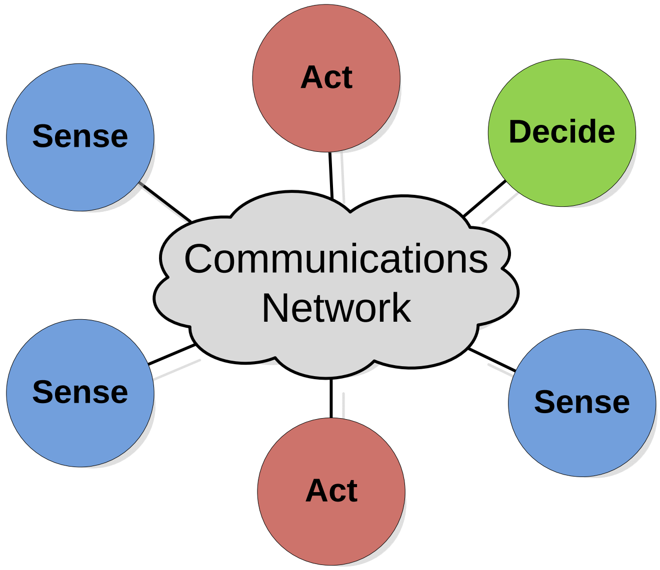


Figure 7 Sense, Decide, Act Nodes

## C. INTEROPERABILITY

### 1. Buddenberg's Interoperability Reference Model (BIRM)

Buddenberg's Interoperability Reference Model[36] organizes the interoperability of information systems into seven layers:

(7) Doctrinal

(6) Cognitive/Shared SA

(5) Procedures

(4) Processes

(3) Data Elements

(2) Modularity

(1) Internetworkability

36 Rex Buddenberg, "Toward an Interoperability Reference Model." *Critical Issues in C4I.* Fairfax, VA: AFCEA-GMU, 2008. 1-4.

Layers 3-7 are beyond the scope of this thesis. Layer-1 (Inter-networkability) is pertinent to defining the characteristics of the communication network that connects the *sense*, *decide*, and *act* functions of an information system. Layer-2 (Modularity) prescribes the architectural blueprints from which the endpoint devices must be designed in order to provide separate and independent *sense*, *decide*, and *act* functions.[37]

Buddenberg explains that modularity is achieved in two steps:

1) Decoupling of end systems from the communication network, which enables the reuse or interchanging of the end systems without changing the communications network.

2) Designing modularity between end systems. Step 2 allows for the “use of a Sense module from one information system to feed data to a Decision module in another information system.[38]

Inter-networking is the ability of an information system to be concatenated together using routers. That is, in order for a communication networks to be interoperable, they must be Layer-3-capable. Tactical networks, of which individual nodes are not Layer-3-capable, require a gateway device to internetwork with the GIG. For example, the packaged and deployable USMC Combat Operations Center made by General Dynamics,[39] requires a rack-mounted unit to convert single-channel radio networks into IP-voice for battalion and higher coordination.

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[37] Rex Buddenberg, "Toward an Interoperability Reference Model." *Critical Issues in C4I.* Fairfax, VA: AFCEA-GMU, 2008. 1-4.

[38] Ibid.

[39] Combat Operations Center, General Dynamics C4 Systems. http://www.gdc4s.com/content/detail.cfm?item=58543087-c533-457b-833c-deb873b09c5a. (Accessed May 2009).

### 2. Architecture

Buddenberg's architecture concepts are based on two principles:

1. All end systems in/on a platform are connected to the node's Local Area Network (LAN)
2. Wide Area Networks (WANs) must be routable networks.[40]

We are applying Principle #2 to tactical wireless networks. Buddenberg explains that for Principle #1, the inverse is true: "end systems do not have radio interfaces-those are all on the other side of a router."[41]

Buddenberg explains that the interfaces of all end systems on the network should adhere to the "Good Network Citizens" concept. This concept requires that endpoint devices must have the following interfaces:

1) LAN Interface-Ensures the ability to network the device's information.

2) Packaging Interface-Ensures that data will be organized into fields such as MIME or XML. Also lays the foundation for security.

3) Public Key Infrastructure (PKI) Interface-Enables data security.

4) Quality of Service (QoS) Interface-Enables differential service at Layer-3, such as Voice over Internet Protocol (VoIP) and video requirements.

5.) Management Interface-Enables remote operation and management of endpoint devices to truly realize NCW.

## D. TWO PRIMARY ELEMENTS OF THE INFORMATION SYSTEM

The information system can be evaluated from the perspective of two primary elements: 1) the endpoint devices and 2) the communications network. The requirements for endpoint devices can be evaluated through Principle #1 of

[40] Rex Buddenberg, *Information Systems Interoperability.* 2009.

[41] Ibid.

Buddenberg's architecture principles, while the requirements for the communications network can be evaluated through Principle #2. The overarching requirement for both of these elements is that they are designed to achieve interoperability. The endpoint devices must be interoperable with each other and interoperable with the communications network. Consequently, the communications network must be interoperable with the endpoint devices it will host, but it must also be interoperable with other networks. More specifically, any tactical communications network must be capable of connecting with another tactical network to form an internetwork. The following two chapters will examine the necessary characteristics and requirements of these two primary elements and how they can be defined to ensure a viable, scalable, and robust information system capable of enabling ECO.

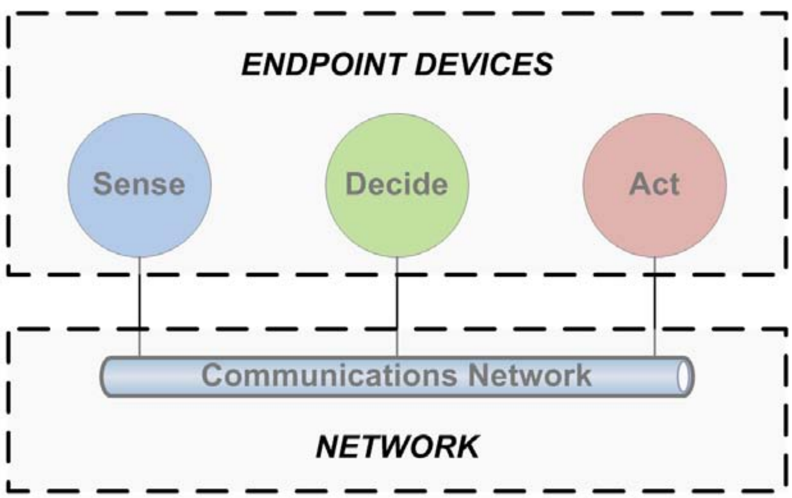


Figure 8 Two Primary Elements of Architecture

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# III. NETWORK REQUIREMENTS

## A. LAYER 3 REQUIREMENTS

### 1. Interoperability

To discuss interoperability as it pertains to network requirements, it is important to revisit the first Layer (Inter-networking) in the BIRM described in Chapter II. Buddenberg defines inter-networking as the ability of an information system to be concatenated together using routers.[42] That is, in order for a communication networks to be interoperable, they must be Layer-3-capable. In the case of small units working in distributed environments, we want to ensure that any node in the network is interoperable. Principle #2 of Buddenberg's Interoperability Architecture states that WANs must be routable networks. We are applying Principle #2 to all nodes on the tactical mesh network. The reason for this is clear. In a dynamic network topology, there will be no fixed gateways or nodes that we know will always be on the boundary of a WAN concatenating the network with other networks to form an internetwork. Therefore, in order for the nodes of a tactical mesh network to be interoperable, they must be Layer-3 (International Standards Organization Model) capable.

Information Systems (Network) Requirement:

- Every node in a tactical mesh network must be a router.

### 2. Extending the GIG (Convergence Layer)

According to the DoD Chief Information Officer (CIO) GIG Architectural Vision[43], "an IP-based network infrastructure is the foundation of end-to-end

[42] Rex Buddenberg,"Toward an Interoperability Reference Model." *Critical Issues in C4I.* Fairfax, VA: AFCEA-GMU, 2008. 1-4.

[43] John G. Grimes, Department of Defense Global Information Grid Architectural Vision. DoD CIO Vision Report, Assistant Secretary of Defense Networks & Information Integration-Chief Information Officer, Department of Defense, Washington: DoD CIO, 2007.

interoperability in the target GIG." The document describes the IP-based network as the "Convergence Layer." The document also explains that "underlying this internetworking layer are all types of DoD-relevant physical transport media and technologies." In other words, the IP-based Convergence Layer is the place in the GIG that different types of network architectures are linked together. For example, copper cabling networks, fiber-optic networks, Satellite Communications (SATCOM), and tactical wireless networks are internetworked at the IP-based Convergence Layer.

Millions of dollars have been spent by the DoD in solving the problem of internetworking disparate communications networks.[44] Solutions to this convergence problem are many and pervasive throughout DoD network initiatives. They range from designing JTRS devices that combine more than 16 different types of waveforms[45] into a limited IP-based capability to gateway devices that converge copper cabling telephone systems with IP-based DoD backbones.

As is stated in the DoD's Architectural Vision, the GIG encompasses all forms of tactical networks, to include Layer-3 data networks, analog and digital telephone networks, and simple radio networks. This thesis posits the solution of extending not just the GIG, but the IP-based Convergence Layer to the lowest tactical level, the individual Marine. Applied to Buddenberg's Information Systems Model, the IP-based network would be the communications network that connects the sense, decide, and act endpoint devices of the tactical information system. This concept differs from existing and emerging tactical network technologies such as the Marine Corps' Warfighter Information Network-Expeditionary (WIN-X) program[46] and JTRS in that it does not create another

[44] Paul Schmidle and Nathan Brinker, "Standards Based Collaboration." *Command and Control Research and Technology Symposium.* San Diego: Command & Control Research Program, 2004. 12.

[45] JTRS, JPEO, "Joint Tactical Radio System (JTRS) Joint Executive Program Office (JPEO)." *Fact Sheet.* San Diego: JTRS JPEO, April 4, 2008.

[46] C4, USMC, *Warfighter Information Network-Expeditionary WIN-X.* Headquarters Marine Corps Brief, Quantico: USMC C4, 2008.

disparate network that must be converged at the Layer-3 via specialized gateways. It simply extends the Layer-3 to the individual Marine. That is, it extends the IP-based Convergence Layer.

Information Systems (Network) Requirement:

- Extend the Convergence Layer (Layer-3) to each node (individual Marine).

### 3. Voice and Data Convergence

As outlined above, a Marine infantryman in a distributed environment requires unique communications capabilities in order to conduct those tasks and missions indicative of ECO. To achieve these goals, he requires the capability to communicate via voice and data. Conventional communication platforms adhere to separate voice and data architectures. That is, a Marine is required to carry both a single-channel radio for voice, and a separate device for data capability. This load includes all ancillary items such as antennas, batteries, and cabling.[47]

Emerging tactical network technologies consolidate both digital voice and IP-based data networks into a single device, yet there are additional disadvantages to this approach. Emerging tactical network solutions such as the Harris® AN/PRC-117G[48] and the Trellisware® CHEETAHNET® radios use separate data and voice channels, essentially employing a single device to maintain two different types of communication networks.[49] Both Harris® and Trellisware® employ a time-division multiple access (TDMA) protocol to solve the media sharing problem. Sharing two different channels, or different types of communication network architectures, significantly reduces the throughput of

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[47] Clayton A. Craig and Christopher S. Tsirlis, "Command & Control for Distributed Operations: An Analysis of Possible Technologies, Structure & Employment." *Thesis.* Naval Postgraduate School, June 2007.

[48] Harris Corporation, “AN/PRC-117G(V)1(C)” http://www.rfcomm.harris.com/117G/ (Accessed May 2009).

[49] Harris Corporation, "Advanced Networking Wideband Waveform (ANW2): Overview for the AN/PRC-117G." Harris, Ocobert 2008.

both. Additionally, utilizing TDMA to share channels within the same node reduces data rate and creates overhead which effectively reduces the available data rate, which is minimal to begin with.

In Section A of this chapter (Extending the GIG), it was illustrated that Layer-3 is the foundational Convergence Layer for the GIG; so eventually, the digital voice channel will have to be converged at the IP-layer, when communicating to the battalion-level or above. A practical solution is to simply use a single network architecture, such as an all IP-based network. By employing a common layer network, all transmission media can be dedicated to passing data from a single layer. Additionally, employing a single architecture, allows for a reduction in the combat load and operating complexity for the individual Marine.

The use of an IP-based architecture would require that all voice capability be moved to VoIP. The use of VoIP for tactical voice traffic would require QoS standards. The commercial employment of VoIP has realized vast improvements of QoS standards and the advancement of IP-telephony. Session Initiation Protocol (SIP) is a signaling protocol that is widely used for ensuring QoS in voice and streaming video applications.[50] Secure VoIP is regularly used by deployed forces in Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). In fact, Secure Internet Protocol Router Network (SIPRNET) VoIP systems employing SIP, and managed by Cisco's® CallManager and CallManger Express, are the Marine Corps' preferred means of secure voice communication at the battalion-level and above.[51] Merging tactical company-level and below VoIP networks with existing secure architectures would be a relatively simple integration.

[50] Rosenberg, et al., SIP: Session Initiation Protocol. Request For Comments: 3261, Internet Engineering Task Force, The Internet Society, 2002.

[51] Based on Capt Price's experience managing tactical Marine communication networks in OIF 05-07.

Other tactical advantages in the use of an all Layer-3-capable platform include the reduction in the requirement of IP processing. All end-to-end services are delivered over an IP architecture relying on IP-based protocols for end-to-end transport, QoS, session management, security, and mobility. Reliance on an all-IP network facilitates easy convergence with other networks, and exploits the rich ecosystem for application development that exists for Layer-3.[52]

Information Systems (Network) Requirement:

- Converge all information to Layer-3 (eliminate separate voice).

### 4. Availability

#### *a. Principles of Availability Engineering*

Buddenberg explains that there are three principles of high availability engineering: 1) Elimination of single points of failure, 2) Reliable crossover, and 3) Prompt detection of failures as they occur.[53] Principles 1 and 2 pertain to the Network Requirements, while Principle 3 is germane to the next chapter, "Endpoint Device Requirements." The elimination of single points of failure may primarily be a provisioning issue; however, it is also an issue of network design. A data network that can handle many-to-many connections, and is capable of dynamically updating and optimizing these connections, has the ability to eliminate single points of failure. This is a given in any established and wired network, but becomes more unique and important in a tactical wireless network that is not mesh-capable. Buddenberg states that the connectionless design of IP meets the requirements of Principle #2: Reliable Crossover.

[52] Full Spectrum, "The WiMAX-e Advantage." http://www.fullspectrumnet.com/fullmaxoverview/thewimaxeadvantage.html (Accessed May 2009).

[53] Rex Buddenberg, Information Systems Interoperability. 2009.

One of the most challenging aspects of wireless mesh networking, is the prospect of controlling and mitigating network congestion. Availability in a tactical mesh network plays a significant role in the attribute of scalability when a network's nodal capacity grows in size to accommodate 42 nodes in a Marine rifle platoon. Indeed, the Marine Corps' primary tactical network device, the AN/PRC-117G can only connect 10 nodes in a subnet.[54] Principle #3 (prompt detection of failures), and advanced Layer-2 and Layer-3 routing protocols continue to evolve to meet these challenges.

#### *b. Streaming Video*

Certain ECO operations require streaming video applications from endpoint devices. This operational requirement generates relatively heavy data rate requirements for meshed network topologies. Streaming video with a frame rate of 15 frames per second (fps) is generally accepted at the tactical level as the minimally acceptable rate that allows for actionable area-effects targeting and surveillance, although this does not allow for precision targeting nor does it allow for targeting in areas where there is a risk of collateral damage.[55]

Two streaming video assessments (not experiments) were conducted during Tactical Network Topology (TNT) field experiments in 2007 and 2008. The frame rate of 15fps using Windows Media Encoder at a compression ratio of 320 X 240, with an initial data rate of 128 Kilobits per second (Kbps), was employed to stream real-time video over a distance of approximately five miles over three hops. The network employed the Trellisware® CHEETAHNET®,

[54] Harris Corporation, "Advanced Networking Wideband Waveform (ANW2): Overview for the AN/PRC-117G." Harris, October 2008.

[55] Based on Capt Price's extensive experience in the employment and coordination of C4I systems during combat operations (OIF 2004, 2006).

which conducted meshing at Layer-2. As the data rate was degraded from distance and multi-hop overhead, the video was consistently untenable as an operational resource.[56]

A study conducted by the Institute for Telecommunications Science, performed subjective video quality testing to estimate the level of video quality that first responders[57] find acceptable for tactical video applications. It was determined that 384Kbps is the recommended data rate required for streaming video with the H.264 high compression codec.[58] A tactical mesh network with streaming video at this rate would require broadband data rates to also allow for VoIP and other application traffic.

#### *c. VoIP*

G.729, the most commonly used codec for secure VoIP over wireless networks in the Marine Corps[59], requires a bandwidth of 31.2 Kbps over a LAN. If this is applied to three conversations within a Marine squad, it equates to 93.6 Kbps.[60] Keep in mind that if the same scenario were applied to a platoon, the intra-squad communications would not be relevant, since a rifleman is generally not going to be talking to his fire team leader or squad leader and not to his platoon sergeant or platoon commander. To add the scenario network consumption rates up with the simultaneous scenario in the above Streaming

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[56] Capt Bob Price, Distributed Operations Tactical Command & Control (DOTC2) Experiment. Tactical Network Topology 08-2 Experiment after Action Report, Monterey: Naval Postgraduate School, 2008.

[57] The term "first responder" refers to those individuals who in the early stages of an incident are responsible for the protection and preservation of life, property, evidence, and the environment, including emergency response providers as defined in section 2 of the Homeland Security Act of 2002 (6 U.S.C. 101).

[58] Margaret H. Pinsonand, Robert B. Stafford, "Video Performance Requirements for Tactical Video Applications." *IEEE Conference on Technologies for Homeland Security.* Woburn: IEEE, 2007. 85-90.

[59] Based on Capt Price's extensive experience in the installation, operation, and maintenance of communication and information systems during combat operations (OIF 2004, 2006).

[60] Cisco®, "Voice Over IP-Per Call Bandwidth Consumption." *www.cisco.com.* February 2, 2006, http://ww.cisco.com/en/US/tech/tk652/tk698/technologies_tech_note09186a00800 94ae2.shtml (Accessed June 2009).

Video paragraph, you get a total of a (384 Kbps + 93.6 Kbps) 477.6 Kbps data rate requirement. This does not include the overhead of multiple hops necessary in a mesh network. The 500 Kbps estimation can be assumed as the reasonable cost of true NCW at the tactical level. Wideband channels are required for each node to achieve these types of data rates.

Information System (Network) Requirements:

- Each node is capable of handling many-to-many connections.
- Each node is capable of dynamically updating and optimizing its connections.
- The network must use a connectionless stateless design (Layer-3).
- The network must be scalable to large nodal capacities without the need for dedicated router devices.
- Device employs wideband channels to achieve >500Kbps per node.

## B. LAYER 2 REQUIREMENTS

### 1. Tactical Mobile Mesh

Tactical mobile mesh networks are wireless communication networks characterized by: harsh propagation channels and interference, frequent and rapid changes in the network topology, the requirement for very robust, low latency multimedia information decimation, and no centralized network control.

These features distinguish such networks from mesh networks (stable network topology), sensor networks (low data rate, delay tolerant), and ad hoc networks (relatively benign RF environments).[61]

### *a. Providing More Combat Powers*

The value of a tactical mesh network may not be as easily understood relative to the value of a commercial network. Metcalfe's Law states that in a communications network with *n* members or nodes, each can make (*n*-1) connections with other participants. Metcalfe states that the total value of that network is proportional to *n*(*n*-1). The intent of Metcalfe's law was to determine the value of a network as it relates to the cost of the network, and at what point the exponential curve of the network value would overcome the linear growth of network cost in a commercial telecommunications industry.[62]

Current tactical networks are obviously missing the boat when it comes to building upon the idea of increasing combat power by increasing nodal connectivity. In order to truly exploit the exponential increase in combat power by increasing network connections, every node must be on the same network. That is, the ideal network topology would provide one internetwork that provides connectivity across the entire battlespace. By employing disparate networks, single-channel radio for an infantry squad, and an IP-based data network over Wireless Point-to-Point Link (WPPL)[63] for intelligence units, then the "n" in the Law remains at small values.

Metcalfe's Law can be applied to tactical networks, although the value of a tactical network must be examined from a different perspective. Obviously, a tactical network's value should not be measured by cost. More

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[61] Adam Blair, Thomas Brown, Keith M.Chugg, and Mark Johnson. "Tactical Mobile Mesh Network System Design." *Military Communications Conference (MILCOM).* Orlando, FL: IEEE, 2007. 1-7.

[62] George Gilder. "Metcalfe's Law and Legacy." *Forbes ASAP*, September 13, 1993.

[63] WPPL is a wireless point-to-point link that provides secure line-of-sight/non-line-of-sight RF communications over terrestrial microwave radio links at distances extending up to 35 miles. WPPL was developed by TeleCommunication Systems.

appropriately, the value of a tactical network should be measured in its ability to aid in the accomplishment of a military unit's mission. In terms of a Marine squad, that mission is to, "locate, close with, and destroy the enemy, by fire and maneuver, or repel the enemy assault by fire and close combat." So the value of a tactical network would be its ability to support this mission. In a widely distributed and decentralized squad layout, any one of the Marines or nodes could be of the highest importance, as any one of the Marines might have "eyes-on" a potential threat or target. Or, any one of the squad members might be in a position to act as a network relay link to the rest of his squad. Additionally, the network status of each node would change rapidly in the course of an operation. So, in a dynamic combat environment, all network links or connections would have equal value as they relate to the mission.

To determine the value of a squad network employing existing single-channel radio networks, it is necessary to step back and apply an older network valuation method, since the single-channel radio network is essentially a broadcast network and has no mesh network or routing characteristics. In order to evaluate a broadcast network, an older concept can be used. The Sarnoff Law was named after David Sarnoff and is ideally suited to assess the value of broadcast networks, as it was applied to television and radio broadcasts.[64] Sarnoff's Law states that the value of a broadcast network is directly proportional to the number of viewers or listeners. In a single-channel radio network, the Marine that is squeezing the push to talk button on his radio handset is the "broadcaster," while the other members of his squad are the "listeners." In this context, a single-channel radio network has the same characteristics as a television or radio broadcast. A single-channel radio network currently employed by the Marine rifle squad cannot perform switching, or routing, nor is it mesh-capable

[64] David P. Reed, "That Sneaky Exponential—Beyond Metcalfe's Law to the Power of Community Building." *Context*, Spring 1999.

David Reed, an Adjunct Professor at the Massachusetts Institute of Technology Media Lab, has introduced an additional concept (known as Reed's Law) into the valuation of networks. He states that, once networks are combined, new and different nodes within those networks coalesce around common interests and form their own network. He has coined these networks "Group-Forming Networks" or Gin's, which can are akin to social networks that we are now familiar with in the form of Facebook or MySpace™. According to Reed's Law, a network that provides easy group communication creates an additional type of connectivity that scales exponentially with the number of nodes.[65] Reed's Law can be expressed as $2^n$-$n$-1.

More recently, Bob Briscoe, Andrew Odlyzko, and Benjamin Tilly have proposed what they consider a more realistic hypothesis on the value of networks and their interconnectivity. They have applied a valuation method based on the equation $n$ log($n$), where $n$ is the number of nodes in a network. The $n$ log($n$) valuation is based on Zapf's Law, and the authors claim that it is more indicative of actual network company relationships in the marketplace. Zapf's Law explains that network links are ranked in order of the amount of value provided. This concept can be applied to the links in a tactical squad-sized mesh network since at any given time some links may provide more value to the network than others. The $n$ log($n$) valuation is more conservative in the estimation of network value.[66]

Signoff's Law, Metcalfe's Law, Reed's Law, and the $n$ log($n$) Law are applied to a 13-man Marine infantry squad to illustrate the added capability a network provides. To expose the difference in value or capability of a communications network, Signoff's Law is used to illustrate the current use of single-channel radio assets, while the other laws are employed to illustrate the difference in network value provided by interconnected mesh networks. In the

65 David P. Reed, "That Sneaky Exponential—Beyond Metcalfe's Law to the Power of Community Building." *Context*, Spring 1999.

66 Briscoe, Bob, Andrew Odlyzko, and Benjamin Tilly. "Metcalfe's Law is Wrong." IEEE Spectrum, July 2006: 34-39.

below graph, "capability," that is, the capability that a network would provide an infantry squad in the accomplishment of its mission, is substituted for "value."

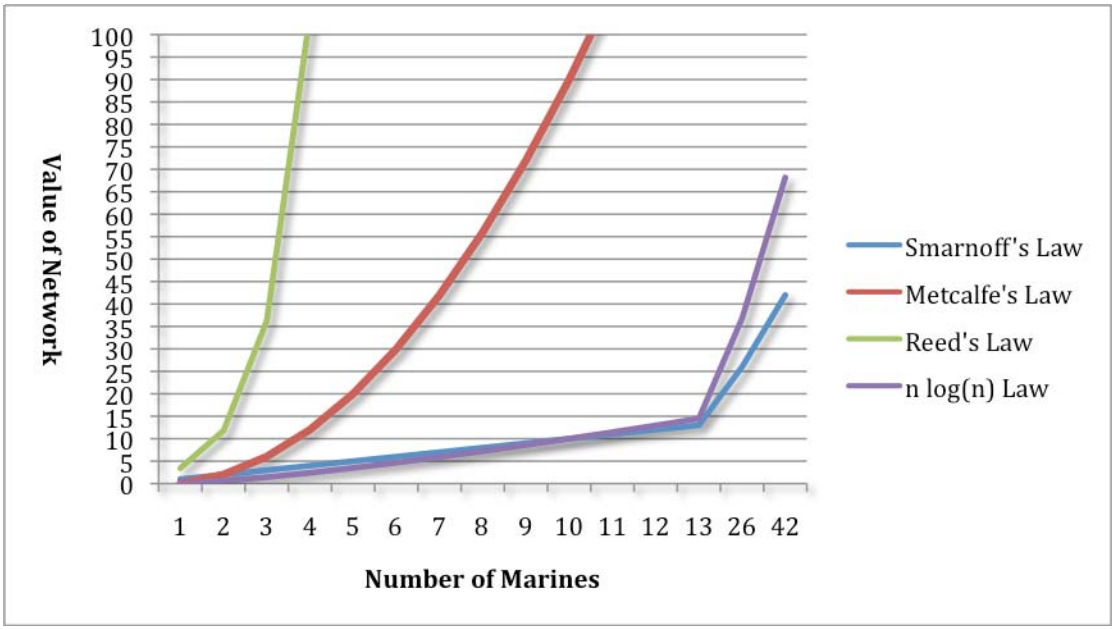


Figure 9 Value of Tactical Mesh Network

The point here is to illustrate that no one can possibly know the added value of employing a network that can connect every node with every other node in range. The value of connecting every Marine with every other Marine, in which there is an operational need, is unknown. As described above, we do know that there will be value, although we do not know the extent of that value. Suffice it say that Marines will find ways of using the capability of internetworked and interoperable information systems in ways we cannot yet envision. In this sense, combat power will be ensured by creating a decentralized architecture that is unrestrained and characterized by infinite possibilities. This is in contrast to current and emerging technologies that are designed to fill a specific function. Instead of constraining operational units with stovepiped capability, we are enabling them with a scalable and robust foundation.

Information Systems (Network) Requirement:

- Each node can be connected directly to each of the others within range.

***b. Mesh Network Allows Dynamic Range Extension***

(1) Every node is a "retrans." An obvious advantage of a mesh network is that every radio/Marine/node is a retransmission (retrans) site. Conventional single-channel capability requires the use of a retransmission site to be established in order to extend the radio network across the battlespace. In this case, a dedicated team of communication Marines is required to move to a position that is ideally suited to establish radio connectivity between two units. Usually this team must position themselves on high ground to achieve the non-line-of-sight (NLOS) required for radio reception between the two units. This becomes an operational requirement and drain on unit resources, as the unit must devote a team of Marines to provide security for the retransmission team. The security requirement becomes even more pronounced when a unit is operating in a widely distributed environment where friendly lines are dispersed as enclaves around firm bases and the area in between these enclaves is hostile.

Establishing a retransmission site requires the use of two single-channel radios, sometimes in the form of a vehicular mounted and amplified system. This reduces the amount of radios for the squad or platoon. In general, the configuration of radios for a retransmission site is at the limit of a communications Marine's competency level. The coordination of Single-Channel Ground and Airborne Radio System (SINCGARS)-based network identification codes adds additional complexity to mission planning and may be lost in the fog of war.

A network with dynamic mesh capability eliminates the requirement of consciously establishing a retransmission site. In an ad hoc mesh network, every node is a retransmission site. A mesh network node is a

continuous and dynamically capable retransmission site and provides de facto range extension, as illustrated in Figure 10, entitled Tactical Range Extension via Mesh Network.

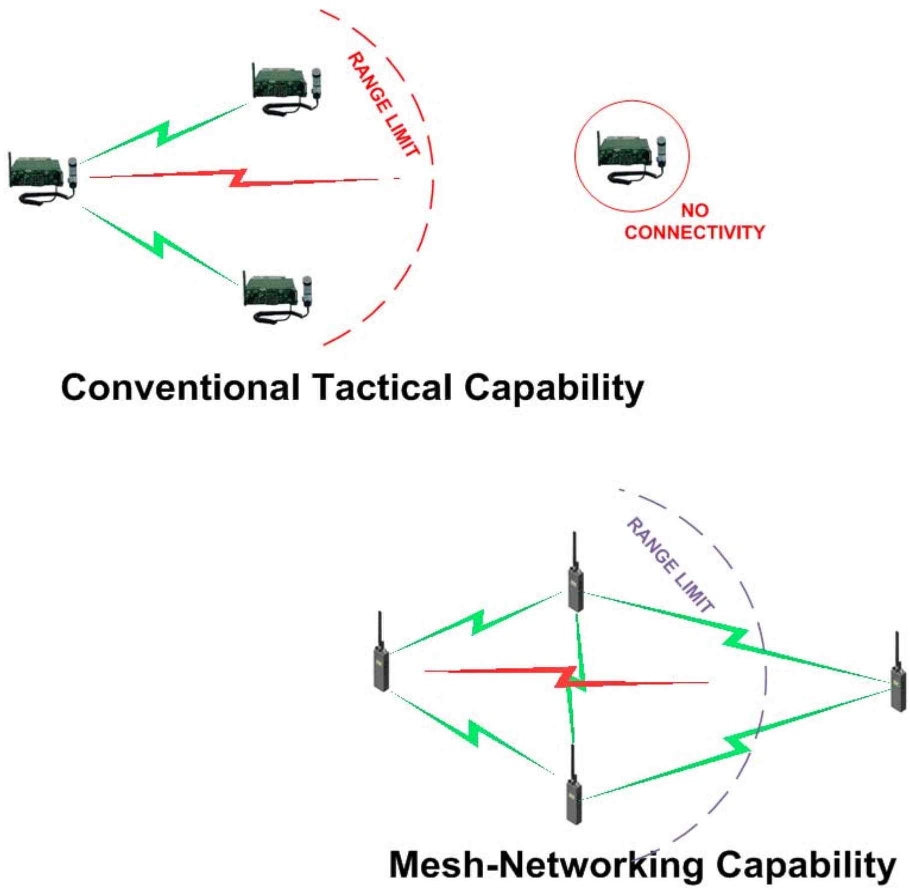


Figure 10 Tactical Range Extension via Mesh Network

Information Systems (Network) Requirement:

- Each node is willing to forward data for other nodes.

(2) Remote Network Relay. The dynamic capability of a mesh network allows for the introduction of remotely operated or autonomous network relay nodes. Several experiments have been conducted by the Naval Postgraduate School, which have demonstrated the capability of mesh network nodes as aerial relays to merge tactical ground networks separated by terrain and distance.

A group of Navy and USMC NPS students teamed up with MCWL to assess the operational feasibility of small handheld wireless mesh-networking radios made by Trellisware®. The intent was to determine the self-healing/forming meshed-networking capabilities of the wireless network design, and to specifically assess the network merging characteristics between multiple distant ground nodes in a DO environment. The Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) Pelican aircraft was used as an aerial relay platform with the intent of demonstrating the feasibility of adapting the Trellisware® radios to the CQ-10A Snow Goose Parafoil platform for follow-on FY08 MCWL experimentation in LOE-5. Network merging experiments were conducted with both aerial and ground network relays during four Pelican flights over a two-day period.

The team successfully demonstrated the feasibility of using an aerial relay platform as a means of merging geographically separate mobile tactical nodes. This capability provides voice and data connectivity to mobile ground troops operating in terrain-limiting NLOS environments. Although systems currently exist to provide this capability, the devices employed in this experiment integrate this capability with much smaller handheld push-to-talk voice systems, similar in profile to the Thales Multiband Inter/Intra Team Radio AN/PRC-148.1[67, 68]

[67] Thales Communications, Inc., “MBITR AN/PRC-148” http://secure.thalescomminc.com/cart2/tcAccessories.asp (Accessed March 2009).

[68] Capt Bob Price, *Distributed Operations Tactical Command & Control (DOTC2) Experiment.* Tactical Network Topology 08-2 Experiment After Action Report, Monterey: Naval Postgraduate School, 2008.

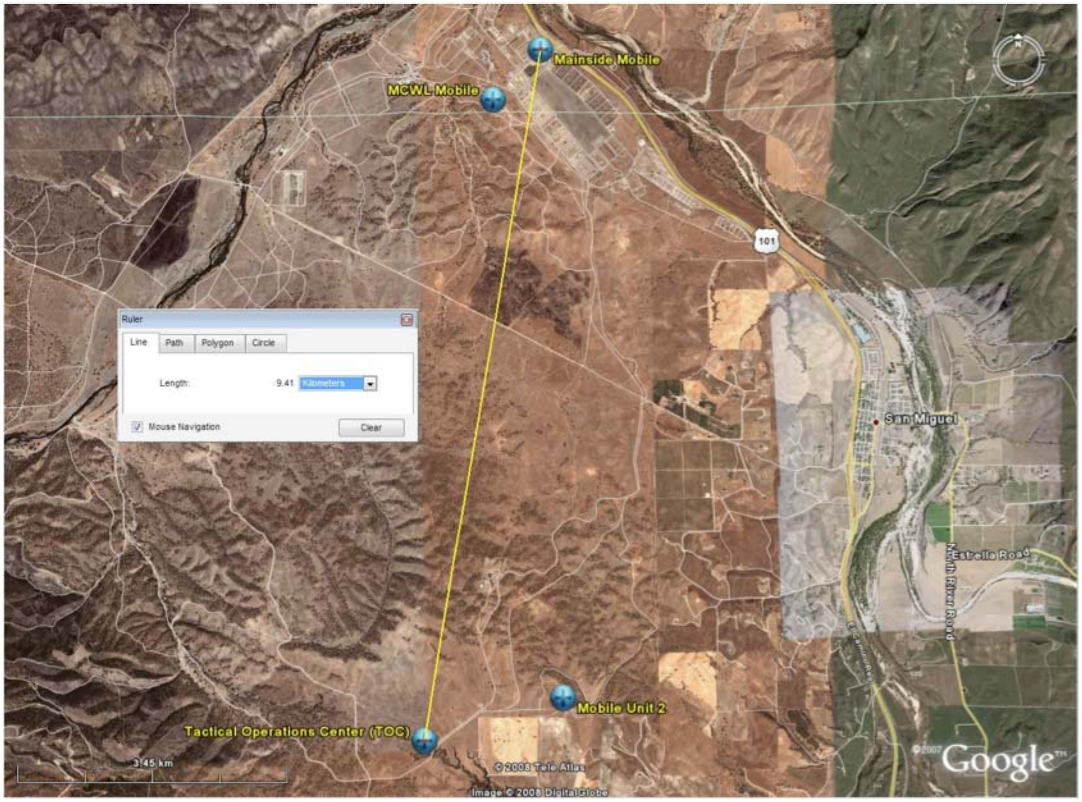


Figure 11      Network Ground Node Locations

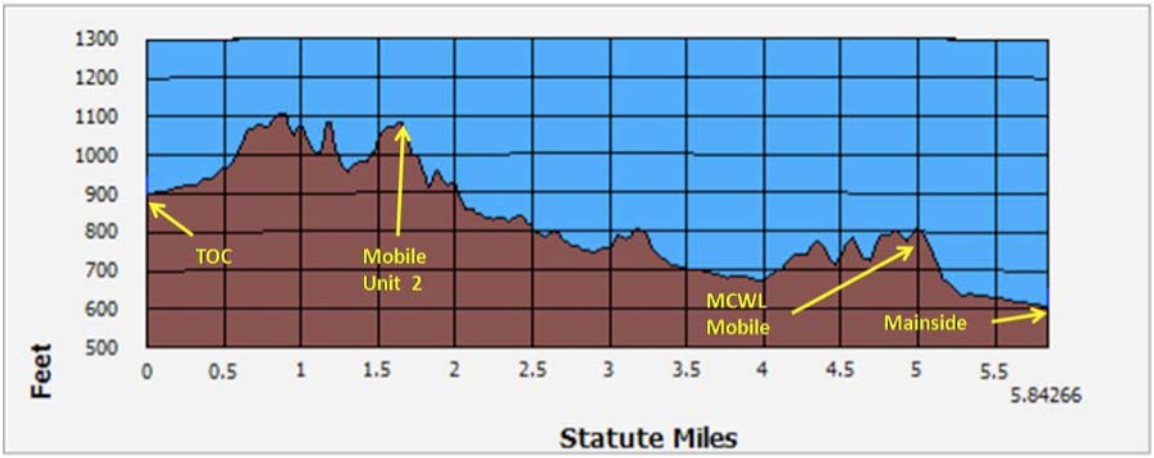


Figure 12      Ground Network Node Elevations

| | Relay Method | Flight Window | Unit | Power | Self-Forming Self-Healing | Network Merge |
|---|---|---|---|---|---|---|
| **Mon, 25 Feb** | Ground | ------------- | Handheld | 2 W | Successful | Successful |
| | | | | | | |
| **Tue, 26 Feb** | Ground | -------------- | Handheld | 2 W | Successful | Marginal Success |
| | Aerial | Morning | Vehicle-Mount | 10 W | Successful | Successful |
| | Aerial | Afternoon | Vehicle-Mount | 10 W | Successful | Successful |
| | | | | | | |
| **Wed, 27 Feb** | Ground | ---------------- | Vehicle-Mount | 10 W | Successful | Successful |
| | Aerial | Morning | Handheld | 2 W | Successful | Unsuccessful |
| | Aerial | Afternoon | Handheld | 2 W | Successful | Unsuccessful |

Figure 13 Test Results

### *c. Mesh Network Enables Decentralized Communication*

The configuration of conventional tactical networks at the infantry company and below has evolved in architecture to mirror the chain of command. Traditionally, the unit structure hierarchy of the fire team, squad, platoon, and company has been the conduit of both operational and informational flow. For a small unit conducting ECO in a distributed environment, this traditional paradigm has changed. As seen in both OIF and OEF, units have been so widely dispersed that they have been independently supported with both indirect fire and logistics apart from their chain of command. They have also operated “laterally” with units that may be transiting their battlespace, without the traditional coordination of their parent unit, whether that is the platoon or company.

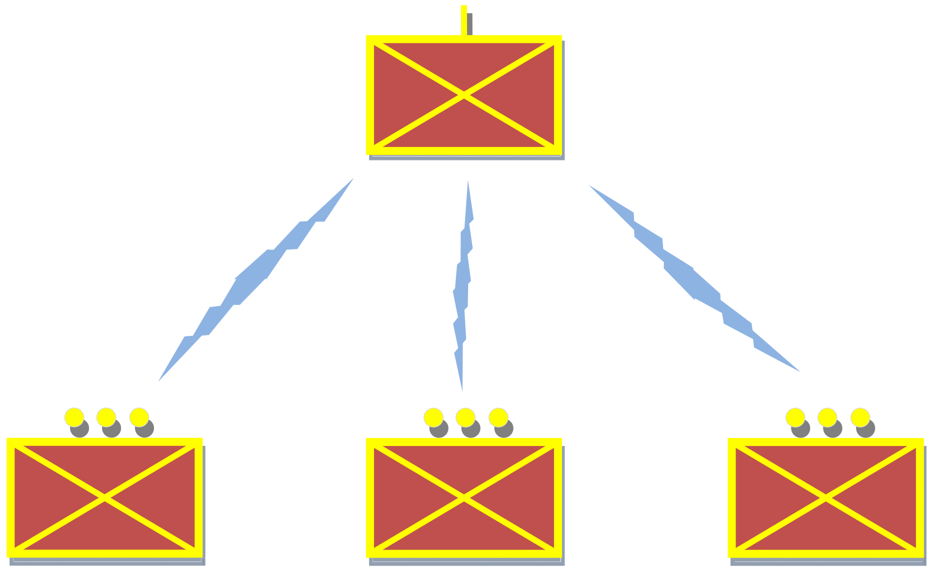

Figure 14 Conventional Single-Channel Radio Network Hierarchy

For example, a squad requesting fire support from battalion heavy mortars would need to coordinate the fire support with its platoon commander, who in turn would coordinate with his company commander, who in turn would coordinate with his battalion fire support officer or weapons platoon commander. Of course, the battalion operations officer would need to be in the loop.

Examining the same situation with a squad that is conducting ECO in a widely distributed environment, we see that the traditional operational flow might depart significantly. In this scenario, a squad is 15 kilometers away from its adjacent squad and platoon headquarters. A section of 155mm howitzers is in general support to the infantry squad's area of operations. The squad leader requests fire support and coordinates with the gun section to achieve effects on target. The operational information flows laterally and is not passed through the squad's chain of command. Figure 15 illustrates this communication flow topology.

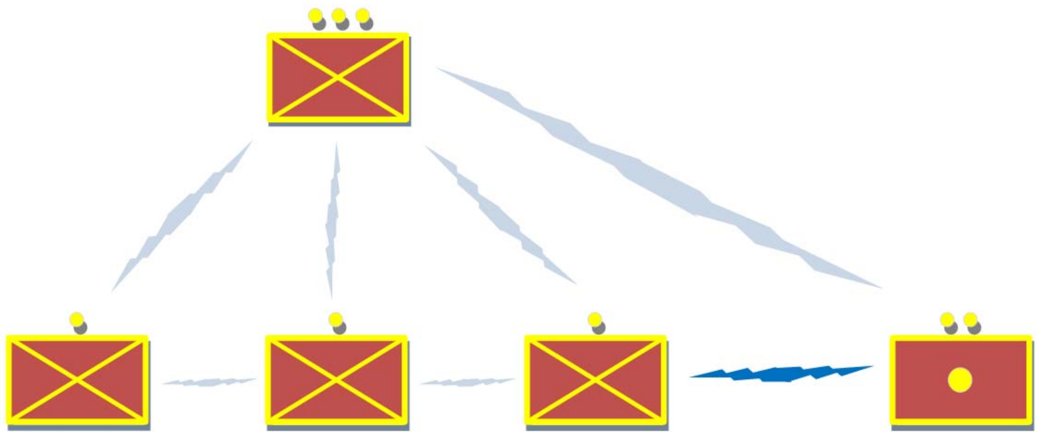

Figure 15 Decentralized Operational Flow Concept

### 2. Stable Media Access Control (MAC)

There are two types of MACs: stable and unstable. An example of an unstable MAC is a contention-based MAC such as IEEE 802.11, which employs carrier-sense multiple access (CSMA). It has been shown that the performance of unstable MACs degrades under overload. In particular, in a highly loaded wireless network, the portion of channel bandwidth wasted due to collisions is significantly high.[69] In other words, a tactical wireless network employing an unstable MAC would show an unacceptable degree of degradation upon breach of its nodal capacity.

Why does this matter? It causes the network to stall. The network capacity of mobile wireless networks is four to six orders of magnitude smaller than wired networks.[70] Wireless networks have much lower data rates than, say, a fiber-optic WAN. An inefficient MAC wastes the very limited bandwidth capacity of wireless networks.

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[69] Xue Yang and Nitin H. Vaidya, *DSCR: A More Stable MAC Protocol for Wireless Networks.* Technical Report, Urbana-Champaign: Electrical and Computer Engineering Department, University of Illinois at Urbana-Champaign, 2002.

[70] Rex Buddenberg, *Information Systems Interoperability.* 2009.

Stable MACs include time-division multiple access (TDMA) and demand-assigned multiple access (DAMA). The primary benefit of a stable MAC is that it is stability under overload, but there are secondary benefits as well. Stable MACs have demonstrated a much more efficient use of bandwidth, and they are also capable of QoS control.[71] The characteristics of a stable MAC are demonstrated in IEEE 802.16.[72]

Information Systems (Network) Requirement:

- Each node must have a stable MAC.

### 3. Ability to Multicast

At the Data Link Layer (DLL) the term multicast refers to a one-to-many distribution of data, or a point-to-multipoint. This describes the ability of a wireless node to transmit data to all other nodes within range at the price of a single transit.[73] This is important for the same reasons as the stable MAC requirement. Wireless networks must use bandwidth as efficiently as possible.

Information Systems (Network) Requirement:

- Each node must have the ability to multicast.

### 4. Fault Detection[74]

SNMP agents must be incorporated into all nodes in order to ensure that network devices are behaving in the most efficient manner. The primary requirement is the detection of faults as they occur, which enables the optimization of network devices. A secondary benefit is that SNMP agents allow

[71] Rex Buddenberg, *Information Systems Interoperability.* 2009.

[72] IEEE Std 802.16-2009.

[73] Rex Buddenberg, Information Systems Interoperability. 2009.

[74] Rex Buddenberg, *Information Systems Interoperability.* 2009.

for the remote and local detection of faults in the node and network segment traffic. This is also important for ensuring the most efficient use of the wireless network's limited bandwidth.

Information Systems (Network) Requirement:

- Each node must be provisioned with an SNMP agent.

## C. LAYER 1 REQUIREMENTS

### 1. Dynamic Frequency Spectrum Capability

The analog or baseband processor of network nodes must be software definable in order to allow for the variation of both channel bandwidth and transmission frequency. The primary reason for this is to enable the range extension of individual nodes. Conventional "high data rate" technologies, such as those specifications for the Joint Tactical Radio System (JTRS) Wideband Networking Waveform (WNW) begin at the 2 GHz range.[75] The Trellisware® CHEETAHNET® radio is capable of UHF spectrum operation. Frequencies in the UHF and SHF range simply cannot achieve the NLOS propagation required in a tactical environment. Only frequencies in the VHF spectrum are capable of NLOS. ECO will be conducted in both variable natural terrains and dense urban environments that will require NLOS capability. Additionally, the software definable capability allows for the variation and dynamic optimization of modulation schemes, which ensures QoS over variable distances between mobile nodes.

Information Systems (Network) Requirement:

- Each node's TX/RX must be software defined.

[75] JTRS, JPEO, "Joint Tactical Radio System (JTRS) Joint Executive Program Office (JPEO)." *Fact Sheet.* San Diego: JTRS JPEO, April 2008.

### 2. Separation of ISO Layer Functionality

Another important aspect of modifiability in the design of the network is the use of communications technologies. Wireless technologies will inevitably be improved to provide greater data rate and more efficient use of the Physical (PHY) and Media Access Control (MAC) layers. In fact, more and more cross-layer approaches are being employed to advance the capability of wireless mesh technologies.[76] In a wireless mesh network, it is essential to design the nodes such that they can be modified. In a network sense, this implies that, while the PHY and MAC layers will most certainly change, the routable capability of the node must stay the same. In the architectural design proposed by this thesis, the router part of the node can be interchanged with the transmission system. More specifically, the PHY and MAC layer functionality should be separated from the node's router. This does not necessarily mean that a transmission system must be physically separate from a router, but the router portion of a Marine's network device should definitely be interchangeable with the transmission section of the device.

This approach ensures modifiability and allows for an evolutionary readiness and flexibility of future advances in both the routing capability and the transmission capability. The Internet has been served well by this approach, and has allowed for significant innovation across all layers of the largest internetwork. This modifiability approach will also allow for the technological inadequacies of current transmission systems and the difficult problem of achieving both the ability to transmit Beyond Line of Sight (BLOS) while maintaining a sufficient amount of data rate, though great advancements have been achieved recently. To elaborate, a Marine would be able to swap out a Very High Frequency (VHF)/Ultra High Frequency (UHF) transmission system for a Super High Frequency (SHF)/Extremely High Frequency (EHF) transmission system in order

[76] Adam Blair, Thomas Brown, Keith M. Chugg, Mark Johnson, "Tactical Mobile Mesh Network System Design." *Military Communications Conference (MILCOM).* Orlando, FL: IEEE, 2007. 1-7.

to communicate through a satellite. This enables an individual node to maintain the same network, while achieving a different and more flexible PHY layer capability.

Information System (Network) Requirements:

- Each node's transmission system must be logically separate from its router.

## D. INFRASTRUCTURE PROTECTION REQUIREMENTS

Infrastructure protection is a network requirement that crosses both Layers 1 and 2 of the ISO model. Infrastructure cannot be confused with "content protection" which is provided at the higher layers. Infrastructure protection can be characterized by security measures such as theft of service, denial of service, traffic analysis, traffic flow analysis, low probability of detection, transmission security, and jam resistance. All of these are important for a combat environment.

Information Systems (Network) Requirement:

- Each node provides infrastructure protection.

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# IV. ENDPOINT DEVICE REQUIREMENTS

A key aspect of Buddenberg's Interoperability Reference Model applies to the endpoint devices. Layer-2 (Modularity) prescribes the architectural blueprints from which the endpoint devices must be designed in order to provide separate and independent sense, decide, and act functions.[77] Endpoint device modularity is achieved by decoupling them from the network. More specifically, the endpoint devices must be located behind a node's router, effectively residing on the node's LAN. This allows for the ability to interchange endpoint devices behind the router, leaving the network unchanged.

The other important aspect of achieving interoperability among endpoint devices is to design them to be modular in relation to each other. This is accomplished by designing endpoint devices to adhere to the "Good Network Citizens" concept as mentioned in Chapter II. To reiterate the concept, all endpoint devices must have a LAN, Packaging, PKI, QoS, and management interface. These interfaces ensure modularity by providing an ability to network the device's information, organizing the data, provide data security, provide quality of service, and to manage the device itself.[78]

<u>Information System (Endpoint Device) Requirements</u>:

- Endpoint Devices must have a LAN interface.
- Endpoint Devices must have a Packaging interface.
- Endpoint Devices must have a PKI interface.
- Endpoint Devices must have a QoS interface.
- Endpoint Devices must have a Management interface.

77 Rex Buddenberg, Information Systems Interoperability. 2009.

78 Ibid.

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# V. INFORMATION SYSTEM REQUIREMENTS SUMMARY

## A. NETWORK REQUIREMENTS

### 1. Layer-3 Requirements

- Every node in a tactical mesh network must be a router.
- Extend the Convergence Layer (Layer-3) to each node (individual Marine).
- Converge all information to Layer 3 (eliminate separate voice).
- Each node is capable of dynamically updating and optimizing its connections.
- The network must use a connectionless stateless design (Layer-3 IP).
- The network must be scalable to large nodal capacities without the need for additional dedicated router devices.
- Device employs wideband channels to achieve >500Kbps per node.

### 2. Layer-2 Requirements

- Each node can be connected directly to each of the others within range.
- Each node is willing to forward data for other nodes.
- Each node is capable of handling many-to-many connections.
- Each node must have a stable MAC.
- Each node must have the ability to multicast.
- Each node must be provisioned with an SNMP agent.

### 3. Layer-1 Requirements

- Each node's transmission system must be software defined.
- Each node's transmission system must be logically separate from its router.

### 4. Infrastructure Protection Requirements

- Each node provides infrastructure protection.

## B. ENDPOINT DEVICE REQUIREMENTS

1. Endpoint Devices must have a LAN interface.
2. Endpoint Devices must have a Packaging interface.
3. Endpoint Devices must have a PKI interface.
4. Endpoint Devices must have a QoS interface.
5. Endpoint Devices must have a Management interface.

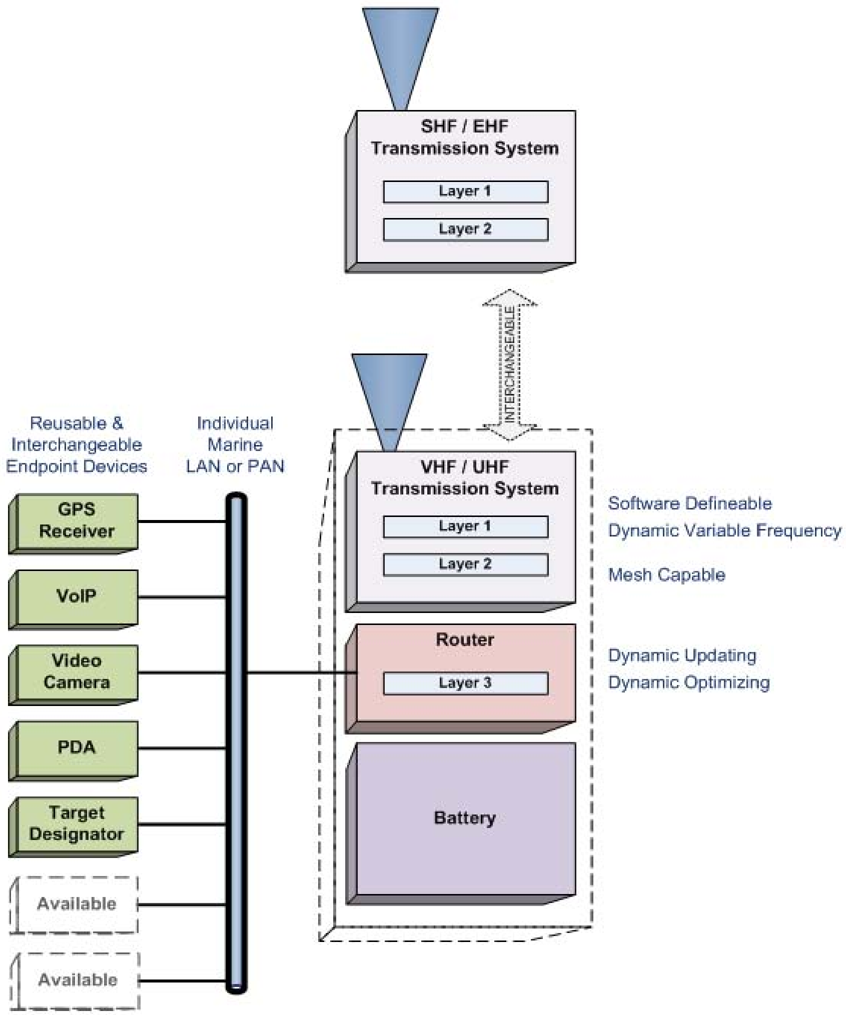


Figure 16 Individual Marine Network Device Concept

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# VI. OPERATIONAL CAPABILITY REQUIREMENTS

Before attempting to identify an optimal communication solution that would enable ECO, the information system requirements must first reach a point of concurrence from the senior leadership throughout the Marine Corps on what additive capability the ECO company needs to bring to the MAGTF Commander to address full spectrum operations across all battlefield functions. A list of ECO concept-based requirements was approved and presented by MCWL to the Marine Corps Infantry Operational Advisory Group (IOAG) in October of 2008 after being approved by the Commandant of the Marine Corps.[79] Selected approved requirements will be discussed across each warfighting function and illustrated with services that would be enabled by an optimal ECO communication solution that is not currently organic to a conventional infantry company table of organization and equipment. The selected function requirements are not necessarily the most important requirements or highest priorities; however, the authors targeted most of the respective requirements because they were defined well enough to tether to available communication services in an enhanced network solution.

These capabilities are similar to those identified in the C2ID CAPSET V Study. The CAPSET V study closely mirrors the capabilities identified by MCWL, but it also elaborates on desired characteristics of a CAPSET V information system.[80] It is important to note that the small unit, as identified in the CAPSET V study, are the same units that would conduct ECO, and, as such, the capabilities identified by both MCCDC's C2ID and the MCWL will be almost

[79] Marine Corps Warfighting Laboratory, "Enhanced Company Operations" brief presented to the Infantry Operational Advisory Group. October 22, 2008. Slide 4.

[80] (C2ID), Command and Control Integration Division, Combat Operations Center (COC) Study Capability Set (CAPSET) V for Marine Corps Air-Ground Task Force (MAGTF) Command and Control (C2). Doctrinal Study, Marine Corps Combat Development Command (MCCDC), United States Marine Corps, Woodbridge: Computer Sciences Corporation, 2008, ES-1.

identical. There are slight differences in the degree and scope of the capability requirements, as some requirements identified by the MCWL are unique to ECO.

## A. MANEUVER

The optimal communication solution would leverage not only more efficient adjustments across the spectrum of operations; it should streamline and minimize redundant and extraneous coordination with adjacent units across all operations. A squad operating over dispersed terrain with large frontages would often transit across or amidst adjacent units in noncontiguous sectors. Current communication limitations require pre-coordination between the units and their respective higher headquarters to coordinate network identification, call signs, frequencies, timing, encryption, PLI, etc. Given the fluid nature of combat operations, the battlespace is continuously changing with adaptive adversaries. Current RF communications lack the flexibility to maintain SA in dynamically changing situations. Safe passage of lines between units is often relegated to visual identification and often without advance notice. Even within visual identification of friendly units, their RF networks are often unable to link and communicate without pre-coordination and require vertical coordination through their respective higher headquarters.

In this scenario, the information system would need to sense PLI, either from a GPS satellite, or from a fellow unit member. The information system would then transmit that data from the position location sensor, via the network, to another Marine. The network does not need to know what the information is, only where it needs to go. The sensor (endpoint) on another Marine would certainly need to recognize the information and be able to interpret and decide on it. To coordinate maneuver with adjacent units, the unit would require the capability to not only sense and coordinate where its own Marines are, but to also coordinate with units that are not on its own internetwork. This would require sense and decide nodes passing data over the network. It would also require a network that was capable of efficient interoperability and authentication.

A desired information system would automatically self-synchronize and bridge their networks when identifiable nodes were within transmission range. Each node should be able to communicate with all other nodes on the network. Current single-channel radio systems across adjacent units or transiting units often can dedicate only one node, e.g., the convoy commander's vehicle, for communication with adjacent units while the remainder of the mobile unit communicates via a separate decoupled net. Self-forming, self-healing, mesh networks would significantly minimize the amount of pre-coordination necessary and would be more resilient to dynamic environments and unpredictable conditions. The additive capabilities provided would enable units operating within the same area of operation to quickly and easily communicate.

## B. FIRES

Capability Requirement: Continue to explore means to provide greater aviation fires support to company and below units.[81]

One of the challenges at the tactical small-unit level is requesting and coordinating supporting arms fire. Disparate RF communication systems in current operations require disparate and incompatible radio systems that require advance coordination with higher units. This inflexibility in dynamic situations greatly diminishes a unit's ability to effectively call for accurate fire while ensuring the safety of the distributed ECO unit. The communication solution should accommodate disparate waveforms that are transparent to the network users. Shared PLI between air and ground units decreases fratricide incidents and increases the SA of all networked nodes that may provide additional fire support assets. The enhanced SA is transmitted back to the higher headquarters to update the common operating picture with real-time updates.

[81] Marine Corps Warfighting Laboratory, "Enhanced Company Operations" brief presented to the Infantry Operational Advisory Group. October 22, 2008. Slide 10.

In this scenario, SA comes in the form of position/location sense nodes that must pass information over the network between disparate units. An aircraft would initially be on a completely different network than the ground unit for which it is providing close air support (CAS). Regardless, the ground unit must be able to pass and receive sensory data over the network. This requires a highly interoperable communications network; one that is communicating the same type of data. A decide node might also be used in order to prevent fratricide. A decide node on the aircraft would receive data from sense nodes and inform the pilot that he can safely prosecute a target without endangering ground forces. Additionally, fire control data, such as target coordinates, Identification of Friend or Foe (IFF), and available assets, must be shared among disparate units in order to effectively prosecute a target and mitigate fratricide. A possible scenario might involve the sense nodes of 1st Squad identifying a target, passing that data to 2nd Squad which requests and directs fire support from an artillery battery. This conveys the need for the information systems of all acting units to be capable of communicating and sharing data over the same internetwork.

## C. INTELLIGENCE

Capability Requirement: Establish the ability to employ sensors at the company and platoon level using organic personnel.[82]

The optimal communication network solution would provide network access down to the platoon level that would facilitate the collection and dissemination of biometric data with real-time database or decision support services. A fully networked solution enables data transfer of immediate query and response transmissions to relay sensor data and provide decision makers at the lowest tactical level enhanced SA. Current RF communications at the company level lack the data capability and reach over distributed distances to communicate with higher headquarters where the biometric databases reside.

[82] Marine Corps Warfighting Laboratory, "Enhanced Company Operations" brief presented to the Infantry Operational Advisory Group. October 2008. Slide 7.

The current limitations result in significant time delay in the processing of collected sensor data. Delays of mere minutes in the rapidly shifting battlespace often result in fleeting or lost opportunities.

Applying the sense-decide-act model of information systems, we can easily recognize that each of these sense nodes must possess a modular data interface. This data interface must package the information such that it can be transmitted over the entirety of the GIG. Another user scenario might be a squad conducting a planned patrol over a distributed area. In this instance, the squad might identify Conditions of Interest (COI) that it would need or want to know about as it is traversing an area. For example, it would want to know of any enemy activity along its patrol route. Perhaps an aerial sensor node identifies a vehicle moving to intersect the squad route. The sensor communicates that information to a decision support service. The decision support service (decide node) recognizes this information as a COI previously input by the squad and transmits a warning to the squad leader. Or, if the vehicle is positively identified as an enemy target, the decide node informs a remote weapon (act node), which then prosecutes the target.

## D. COMMAND AND CONTROL

Capability Requirement: Limited Capabilities—Over the Horizon/On the Move Data Communications to the Platoon (Squad) Level[83]

Capability Requirement: Selected Capabilities—Over the Horizon Digital Communications at the Company Level[84]

Both of the stated C2 concept-based requirements would be fully realized, and integral, to a usable ECO communication solution. The routable solution would provide a long-haul reach that would bridge dispersed nodes throughout the AO with higher headquarters. The data capability would be a critical

[83] Marine Corps Warfighting Laboratory, "Enhanced Company Operations" brief presented to the Infantry Operational Advisory Group. October 22, 2008. Slide 5.

[84] Ibid., Slide 5.

requirement in routing VoIP. This Over the Horizon reach back with higher headquarters would facilitate real-time SA within the tactical network and on the common operating picture.

## E. LOGISTICS

Capability Requirement: Establish the capability of the Company to more effectively plan, manage, track, receive and distribute logistics.[85]

Capability Requirement: Develop the means to deliver tailored logistics packages directly to the platoon and squad levels from battalion/MAGTF sources.[86]

Capability Requirement: Establish the capability to employ multiple modes of re-supply.[87]

Current limitations with single-channel radios requiring extensive coordination would be overcome with fully networked solutions. The ECO communication solution would bridge this gap enabling numerous additive capabilities. Autonomic logistics would be enabled along with other communication-intensive operations such as re-supply and casualty evacuation.

## F. FORCE PROTECTION

- ECO Requirement: Develop, define and refine medical support for ECO.[88]
- ECO Requirement: Explore new technologies for casualty treatment and evacuation.[89]

[85] Marine Corps Warfighting Laboratory, "Enhanced Company Operations" brief presented to the Infantry Operational Advisory Group. October 22, 2008. Slide 9.

[86] Ibid., Slide 9.

[87] Ibid., Slide 9.

[88] Ibid., Slide 10.

[89] Ibid., Slide 9.

As addressed in the previous warfighting functions, current limitations with single-channel radios require extensive coordination, lack the flexibility to easily scale and are not self-aware. One of the greatest challenges faced by an ECO unit is the significant dispersion from supporting units and the logistical and force protection challenges resulting from sustaining the ECO unit. The ECO communication solution would bridge this gap enabling numerous additive capabilities. Casualty evacuation and re-supply, similar information flow processes, are two of the greatest hurdles to ECO. The authors developed a case study to determine the additive capability and return on investment when comparing the casualty evacuation (CASEVAC) processes between a traditional single-channel RF network and a fully networked, mesh network that would be required for an ECO communication solution. The case study modeled the process after OIF CASEVAC procedures as experienced by one of the authors.

The process was modeled using Savvion Process Modeler software to simulate 2,880 CASEVAC missions using both process models: the traditional RF network, and the enhanced ECO communication solution.

This case study examined a conventional tactical Marine combat unit deployed in theater, outside of the current ECO conceptual construct, tasked with getting a casualty out of a combat area to receive appropriate medical attention. This case study assessed the process flow challenges in getting a casualty from the front line of troops back to the appropriate medical facility in the most expeditious manner during the critical golden hour.[90]

The process begins with a casualty in need of medical support. The organic Navy corpsman with the unit assesses the casualty and determines the level of combat health support needed: level one (Routine), level two (Priority), or level three (Immediate). The action required determines the process flow. The process model used two information flow objectives: first, identify the casualty; and, second, transmit this information to higher headquarters for dedication of

[90] The most critical period of time for anyone who is seriously injured is the "golden hour"—the interval between the occurrence of the injury and the administration of appropriate aid.

appropriate assets for extraction. The processes modeled used identical procedures with different information flow processes. The single greatest limiting element to the single-channel voice communication model was the communication latency that lacked a data capability and was not networked to all appropriate stakeholders. Further, the hierarchical construct of the stakeholders resulted in an inefficient information flow. The value of the ECO communication network was that it streamlined the information flow process with a Layer-3 wireless data network solution utilizing database services to retrieve casualty information and pass data, e.g., medical record, health history, PLI, etc., to key stakeholders, concurrently. Standardized tactical applications enhanced the information push/pull focusing on the valued information, i.e., minimal elements from the entire file record in its information stream. All tactical coordination was coordinated through the network in which position location information data is shared across nodes in lieu of reporting via voice, eliminating garble, cross-talk and retransmission.

The results of the Savvion process modeling software calculated a 27% efficiency gain in information flow in the ECO communication model. The ECO model resulted in significantly more efficient information flows. The efficient gains were most notable with the instantaneous access to information for all stakeholders, providing real-time updates throughout the process.

# VII. EVALUATION OF CURRENT AND EMERGING DOD TACTICAL COMMUNICATION SYSTEMS

## A. EVALUATION OF NETWORK DEVICES CURRENTLY IN USE

The following information system technologies are currently used by Marine Corps operating forces in tactical units identified for ECO and CAPSET V user capabilities. Capability gaps identified by the Command and Control Integration Division of MCCDC[91] are listed along with those capability gaps as evaluated against the information systems network requirements summarized in Chapter V.

| **AN/PRC-117G**[92] |  |
|---|---|
| **Capability Gaps Identified in the COC Study CAPSET V for MAGTF C2** | |
| ▪ Voice Capable (Analog or Digital) | Capable |
| ▪ Data Capable | Capable |
| ▪ Data Rate | Med |
| ▪ Beyond Line of Sight Capable (VHF & UHF Mode) | Gap |
| ▪ Beyond Line of Sight Capable (DAMA SATCOM Mode) | Capable |
| ▪ Dismountable | Capable |
| ▪ On-The-Move Capable | Capable |

Table 1. AN/PRC-117G Evaluation-Capability Gaps

[91] (C2ID), Command and Control Integration Division, Combat Operations Center (COC) Study Capability Set (CAPSET) V for Marine Corps Air-Ground Task Force (MAGTF) Command and Control (C2). Doctrinal Study, Marine Corps Combat Development Command (MCCDC), United States Marine Corps, Woodbridge: Computer Sciences Corporation, 2008, ES-1.

[92] Harris Corporation, "Advanced Networking Wideband Waveform (ANW2): Overview for the AN/PRC-117G." Harris, October 2008.

| AN/PRC-117G[93] |  |
|---|---|
| **Requirement Gaps Evaluated Against Chapter V Requirements** | |
| ▪ Every node in a tactical mesh network must be a router. | Gap |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Capable |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Capable |
| ▪ Each node is willing to forward data for other nodes. | Gap |
| ▪ Each node is capable of handling many-to-many connections. | Capable |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Capable |
| ▪ The network must use a connectionless stateless design (Layer-3). | Gap |
| ▪ Each node's transmission system must be software defined. | Capable |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for dedicated router devices. | Gap |
| ▪ Each node provides infrastructure protection with a secure MAC. | Capable |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Capable |
| ▪ Each node must have the ability to multicast. | Capable |

Table 2. AN/PRC-117G Evaluation-Requirements Gaps

[93] Harris Corporation, "Advanced Networking Wideband Waveform (ANW2): Overview for the AN/PRC-117G." Harris, October 2008.

| Integrated Intra-Squad Radio (IISR)[94] |  |
| --- | --- |

| Capability Gaps Identified in the COC Study CAPSET V for MAGTF C2 | |
| --- | --- |
| ▪ Voice Capable (Analog or Digital) | Capable |
| ▪ Data Capable | Gap |
| ▪ Data Rate | Low |
| ▪ Beyond Line of Sight Capable | Gap |
| ▪ Dismountable | Capable |
| ▪ On-The-Move Capable | Capable |

Table 3. IISR Evaluation-Capability Gaps

94 Integrated Intra-Squad Radio, PG-12 Communications, Intelligence, & Networking Systems. "PG-12 Tactical Communications." *Marine Corps Systems Command.* http://www.marcorsyscom.usmc.mil/sites/cins/CNS/Tactical%20Radios/IISR.html (Accessed July 2009).

| **Integrated Intra-Squad Radio (IISR)**[95] |  |
|---|---|
| **Requirement Gaps Evaluated Against Chapter V Requirements** | |
| ▪ Every node in a tactical mesh network must be a router. | Gap |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Gap |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Gap |
| ▪ Each node is willing to forward data for other nodes. | Gap |
| ▪ Each node is capable of handling many-to-many connections. | Gap |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Gap |
| ▪ The network must use a connectionless stateless design (Layer-3). | Gap |
| ▪ Each node's transmission system must be software defined. | Capable |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for dedicated router devices. | Gap |
| ▪ Each node provides infrastructure protection. | Gap |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Gap |
| ▪ Each node must have the ability to multicast. | Capable |

Table 4. IISR Evaluation-Requirements Gaps

[95] Integrated Intra-Squad Radio, PG-12 Communications, Intelligence, & Networking Systems. "PG-12 Tactical Communications." *Marine Corps Systems Command.* http://www.marcorsyscom.usmc.mil/sites/cins/CNS/Tactical%20Radios/IISR.html (Accessed July 2009).

| AN/PSC-5[96] |  |
|---|---|

| Capability Gaps Identified in the COC Study CAPSET V for MAGTF C2 | |
|---|---|
| ▪ Voice Capable (Analog or Digital) | Capable |
| ▪ Data Capable | Capable |
| ▪ Data Rate | Med-Low |
| ▪ Beyond Line of Sight Capable | Capable |
| ▪ Dismountable | Capable |
| ▪ On-The-Move Capable | Capable |

Table 5. AN/PSC-5 Evaluation-Capability Gaps

96 Raytheon, "AN/PSC-5 White Paper." *Raytheon.* http://www.raytheon.com/capabilities/rtnwcm/groups/ncs/documents/content/rtn_ncs_products_psc5c_pdf.pdf (Accessed August 2009).

| AN/PSC-5[97] |  |
|---|---|
| **Requirement Gaps Evaluated Against Chapter V Requirements** | |
| ▪ Every node in a tactical mesh network must be a router. | Gap |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Gap |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Gap |
| ▪ Each node is willing to forward data for other nodes. | Gap |
| ▪ Each node is capable of handling many-to-many connections. | Gap |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Gap |
| ▪ The network must use a connectionless stateless design (Layer-3). | Gap |
| ▪ Each node's transmission system must be software defined. | Capable |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for additional dedicated router devices. | Gap |
| ▪ Each node provides infrastructure protection. | Capable |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Capable |
| ▪ Each node must have the ability to multicast. | Capable |

Table 6. AN/PSC-5 Evaluation-Requirements Gaps

97 Raytheon. "AN/PSC-5 White Paper." *Raytheon.* http://www.rayth,on.com/capabilities/rtnwcm/groups/ncs/documents/content/rtn_ncs_products_psc5c_pdf.pdf (Accessed August 2009).

| AN/PRC-150C[98] |  |
|---|---|



| Capability Gaps Identified in the COC Study CAPSET V for MAGTF C2 | |
|---|---|
| ▪ Voice Capable (Analog or Digital) | Capable |
| ▪ Data Capable | Capable |
| ▪ Data Rate | Very Low |
| ▪ Beyond Line of Sight Capable | Capable |
| ▪ Dismountable | Capable |
| ▪ On-The-Move Capable | Capable |

Table 7. AN/PRC-150 Evaluation-Capability Gaps

[98] (C2ID), Command and Control Integration Division. Combat Operations Center (COC) Study Capability Set (CAPSET) V for Marine Corps Air-Ground Task Force (MAGTF) Command and Control (C2). Doctrinal Study, Marine Corps Combat Development Command (MCCDC), United States Marine Corps, Woodbridge: Computer Sciences Corporation, 2008, 15.

| AN/PRC-150C[99] |  |
|---|---|

| Requirement Gaps Evaluated Against Chapter V Requirements | |
|---|---|
| ▪ Every node in a tactical mesh network must be a router. | Gap |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Gap |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Gap |
| ▪ Each node is willing to forward data for other nodes. | Gap |
| ▪ Each node is capable of handling many-to-many connections. | Gap |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Gap |
| ▪ The network must use a connectionless stateless design (Layer-3). | Gap |
| ▪ Each node's transmission system must be software defined. | Gap |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for dedicated router devices. | Gap |
| ▪ Each node provides infrastructure protection. | Gap |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Gap |
| ▪ Each node must have the ability to multicast. | Gap |

Table 8. AN/PRC-150C-Requirements Gaps

[99] (C2ID), Command and Control Integration Division. Combat Operations Center (COC) Study Capability Set (CAPSET) V for Marine Corps Air-Ground Task Force (MAGTF) Command and Control (C2). Doctrinal Study, Marine Corps Combat Development Command (MCCDC), United States Marine Corps, Woodbridge: Computer Sciences Corporation, 2008, 15.

| **Enhanced Position Location Reporting System (EPLRS)**[100] |  |
|---|---|
| **Capability Gaps Identified in the COC Study CAPSET V for MAGTF C2** | |
| ▪ Voice Capable (Analog or Digital) | Gap |
| ▪ Data Capable | Capable |
| ▪ Data Rate | Medium |
| ▪ Beyond Line of Sight Capable | Gap |
| ▪ Dismountable | Gap |
| ▪ On-The-Move Capable | Capable |

Table 9. EPLRS Evaluation-Capability Gaps

[100] (C2ID), Command and Control Integration Division. Combat Operations Center (COC) Study Capabilit, Set (CAPSET) V for Marine Corps Air-Ground Task Force (MAGTF) Command and Control (C2). Doctrinal Study, Marine Corps Combat Development Command (MCCDC), United States Marine Corps, Woodbridge: Computer Sciences Corporation, 2008, 15.

| | |
|---|---|
| **Enhanced Position Location Reporting System (EPLRS)**[101] |  |

| Requirement Gaps Evaluated Against Chapter V Requirements | |
|---|---|
| ▪ Every node in a tactical mesh network must be a router. | Capable |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Gap |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Capable |
| ▪ Each node can be connected directly to each of the others within range. | Capable |
| ▪ Each node is willing to forward data for other nodes. | Gap |
| ▪ Each node is capable of handling many-to-many connections. | Capable |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Gap |
| ▪ The network must use a connectionless stateless design (Layer-3). | Capable |
| ▪ Each node's transmission system must be software defined. | Gap |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for dedicated router devices. | Capable |
| ▪ Each node provides infrastructure protection. | Capable |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Capable |
| ▪ Each node must have the ability to multicast. | Capable |

Table 10. EPLRS Evaluation-Requirements Gaps

[101] (C2ID), Command and Control Integration Division. Combat Operations Center (COC) Study Capability Set (CAPSET) V for Marine Corps Air-Ground Task Force (MAGTF) Command and Control (C2). Doctrinal Study, Marine Corps Combat Development Command (MCCDC), United States Marine Corps, Woodbridge: Computer Sciences Corporation, 2008, 15.

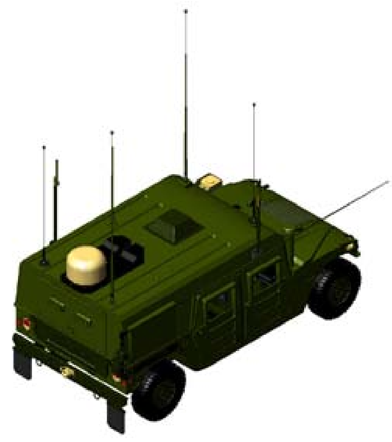
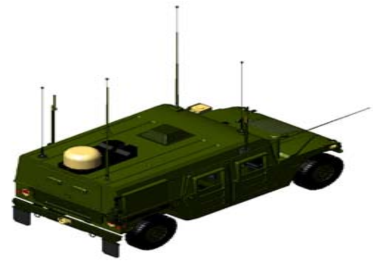
| **Command and Control On-the-Move Network, Digital Over-the-Horizon Relay (CONDOR)**[102] |  |
|---|---|
| **Capability Gaps Identified in the COC Study CAPSET V for MAGTF C2** | |
| ▪ Voice Capable (Analog or Digital) | Gap |
| ▪ Data Capable | Capable |
| ▪ Data Rate | Low |
| ▪ Beyond Line of Sight Capable | Capable |
| ▪ Dismountable | Gap |
| ▪ On-The-Move Capable | Capable |

Table 11. CONDOR Evaluation-Capability Gaps

102 PG-12 Communications, Intelligence, & Networking Systems, "PG-12 Tactical Communications." *Marine Corps Systems Command.* http://images.google.com/imgres?imgurl=http://www.marcorsyscom.usmc.mil/sites/cins/CNS/ (Accessed July 2009).

| | |
|---|---|
| **Command and Control On-the-Move Network, Digital Over-the-Horizon Relay (CONDOR)**[103] |  |

| Requirement Gaps Evaluated Against Chapter V Requirements | |
|---|---|
| ▪ Every node in a tactical mesh network must be a router. | Capable |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Gap |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Gap |
| ▪ Each node is willing to forward data for other nodes. | Gap |
| ▪ Each node is capable of handling many-to-many connections. | Gap |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Gap |
| ▪ The network must use a connectionless stateless design (Layer-3). | Capable |
| ▪ Each node's transmission system must be software defined. | Gap |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for additional dedicated router devices. | Capable |
| ▪ Each node provides infrastructure protection. | Capable |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Capable |
| ▪ Each node must have the ability to multicast. | Gap |

Table 12. CONDOR Evaluation-Capability Gaps

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103 PG-12 Communications, Intelligence, & Networking Systems, "PG-12 Tactical Communications." *Marine Corps Systems Command.* http://images.google.com/imgres?imgurl=http://www.marcorsyscom.usmc.mil/sites/cins/CNS/ (Accessed July 2009).

## B. EVALUATION OF EMERGING NETWORK SYSTEMS

**Warfighter Information Network-Expeditionary (Win-X)**[104] Increment 2 is targeted to provide a tactical network Point of Presence for company and below units.

| Requirement Gaps Evaluated Against Chapter V Requirements | |
|---|---|
| ▪ Voice Capable (Analog or Digital) | Gap |
| ▪ Data Capable | Capable |
| ▪ Device employs wideband channels to achieve >500Kbps per node. | Capable |
| ▪ Beyond Line of Sight Capable | Capable |
| ▪ Dismountable | Gap |
| ▪ On-The-Move Capable (Increment 2) | Capable |
| ▪ Every node in a tactical mesh network must be a router. | Capable |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Capable |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Capable |
| ▪ Each node is willing to forward data for other nodes. | Capable |
| ▪ Each node is capable of handling many-to-many connections. | Capable |
| ▪ Each node is capable of dynamically updating and optimizing connections. | Gap |
| ▪ The network must use a connectionless stateless design (Layer-3). | Gap |
| ▪ Each node's transmission system must be software defined. | Gap |
| ▪ Each node's transmission system must be logically separate from its router. | Capable |

104 C4, USMC, *Warfighter Information Network-Expeditionary WIN-X.* Headquarters Marine Corps Brief, Quantico: USMC C4, 2008.

| | |
|---|---|
| ▪ The network must be scalable to large nodal capacities without the need for additional dedicated router devices. | Gap |
| ▪ Each node provides infrastructure protection. | Capa ble |
| ▪ Each node must be provisioned with an SNMP agent. | Capa ble |
| ▪ Each node must have a stable MAC. | Capa ble |
| ▪ Each node must have the ability to multicast. | Gap |

Table 13. WIN-X Evaluation-Requirements Gaps

| TW-220[105] |  |
|---|---|
| **Capability Gaps Identified in the COC Study CAPSET V for MAGTF C2** | |
| ▪ Voice Capable (Analog or Digital) | Capable |
| ▪ Data Capable | Capable |
| ▪ Device employs wideband channels to achieve >500Kbps per node. | Gap |
| ▪ Beyond Line of Sight Capable | Gap |
| ▪ Dismountable | Capable |
| ▪ On-The-Move Capable | Capable |

Table 14. TW-220 Evaluation-Capability Gaps

[105] Capt Bob Price, *Distributed Operations Tactical Command & Control (DOTC2) Experiment.* Tactical Network Topology 08-2 Experiment After Action Report, Monterey: Naval Postgraduate School, 2008.

| | |
|---|---|
| **TW-220**[106] |  |

| Requirement Gaps Evaluated Against Chapter V Requirements | |
|---|---|
| ▪ Every node in a tactical mesh network must be a router. | Gap |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Gap |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Capable |
| ▪ Each node is willing to forward data for other nodes. | Capable |
| ▪ Each node is capable of handling many-to-many connections. | Capable |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Capable |
| ▪ The network must use a connectionless stateless design (Layer-3). | Gap |
| ▪ Each node's transmission system must be software defined. | Capable |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for additional dedicated router devices. | Capable |
| ▪ Each node provides infrastructure protection. | Capable |
| ▪ Each node must be provisioned with an SNMP agent. | Capable |
| ▪ Each node must have a stable MAC. | Capable |
| ▪ Each node must have the ability to multicast. | Capable |

Table 15. TW-220 Evaluation-Requirements Gaps

106 Capt Bob Price, *Distributed Operations Tactical Command & Control (DOTC2) Experiment.* Tactical Network Topology 08-2 Experiment After Action Report, Monterey: Naval Postgraduate School, 2008.

| **Distributed Tactical Communications System (DTCS)**[107] |  |
|---|---|
| **Requirement Gaps Evaluated Against Chapter V Requirements** | |
| ▪ Voice Capable (Analog or Digital) | Capable |
| ▪ Data Capable | Gap |
| ▪ Device employs wideband channels to achieve >500Kbps per node. | Gap |
| ▪ Beyond Line of Sight Capable | Capable |
| ▪ Dismountable | Capable |
| ▪ On-The-Move Capable (Increment 2) | Capable |
| ▪ Every node in a tactical mesh network must be a router. | Gap |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Gap |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Gap |
| ▪ Each node is willing to forward data for other nodes. | Gap |
| ▪ Each node is capable of dynamically updating and optimizing connections. | Gap |
| ▪ The network must use a connectionless stateless design (Layer-3). | Gap |
| ▪ Each node's transmission system must be software defined. | Capable |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for additional dedicated router devices. | Capable |
| ▪ Each node provides infrastructure protection. | Capable |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Gap |
| ▪ Each node must have the ability to multicast. | Gap |

Table 16. DTCS Evaluation-Requirements Gaps

[107] USMC MCWL, CENTCOM, STRATCOM, NSWC Dahlgren, *Distributed Tactical Communications System.* Joint Capability Technology Demonstration (JCTD) FY09 Candidate, HQMC, APW, 2007.

| **Joint Tactical Radio System (JTRS), Handheld, Manpack, Small Form Fit (HMS), Soldier Radio Waveform (SRW)** [108] |  |
|---|---|
| **Requirement Gaps Evaluated Against Chapter V Requirements** | |
| ▪ Voice Capable (Analog or Digital) | Capable |
| ▪ Data Capable | Capable |
| ▪ Device employs wideband channels to achieve >500Kbps per node. | Gap |
| ▪ Beyond Line of Sight Capable | Capable |
| ▪ Dismountable | Capable |
| ▪ On-The-Move Capable (Increment 2) | Capable |
| ▪ Every node in a tactical mesh network must be a router. | Gap |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Capable |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Gap |
| ▪ Each node can be connected directly to each of the others within range. | Capable |
| ▪ Each node is willing to forward data for other nodes. | Capable |
| ▪ Each node is capable of handling many-to-many connections. | Capable |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Gap |
| ▪ The network must use a connectionless stateless design (Layer-3). | Capable |
| ▪ Each node's transmission system must be software defined. | Capable |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for additional dedicated router devices. | Gap |
| ▪ Each node provides infrastructure protection. | Capable |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Capable |
| ▪ Each node must have the ability to multicast. | Capable |

Table 17. JTRS Evaluation-Requirements Gaps

108 JTRS, JPEO, "Joint Tactical Radio System (JTRS) Joint Executive Program Office (JPEO)." *Fact Sheet.* San Diego: JTRS JPEO, April 2008.

| **Enhanced Position Location Reporting System-Extended Frequency (EPLRS-XF)**[109] |  |
|---|---|
| **Requirement Gaps Evaluated Against Chapter V Requirements** | |
| ▪ Voice Capable (Analog or Digital) | Gap |
| ▪ Data Capable | Capable |
| ▪ Device employs wideband channels to achieve >500Kbps per node. | Capable |
| ▪ Beyond Line of Sight Capable | Gap |
| ▪ Dismountable | Gap |
| ▪ On-The-Move Capable | Gap |
| ▪ Every node in a tactical mesh network must be a router. | Capable |
| ▪ Extend the Convergence Layer to each node (individual Marine). | Gap |
| ▪ Converge all information to Layer 3 (eliminate separate voice). | Capable |
| ▪ Each node can be connected directly to each of the others within range. | Capable |
| ▪ Each node is willing to forward data for other nodes. | Capable |
| ▪ Each node is capable of handling many-to-many connections. | Capable |
| ▪ Each node is capable of dynamically updating and optimizing its connections. | Capable |
| ▪ The network must use a connectionless stateless design (Layer-3). | Capable |
| ▪ Each node's transmission system must be software defined. | Capable |
| ▪ Each node's transmission system must be logically separate from its router. | Gap |
| ▪ The network must be scalable to large nodal capacities without the need for additional dedicated router devices. | Capable |
| ▪ Each node provides infrastructure protection. | Capable |
| ▪ Each node must be provisioned with an SNMP agent. | Gap |
| ▪ Each node must have a stable MAC. | Capable |
| ▪ Each node must have the ability to multicast. | Capable |

Table 18. EPLRS-XF Evaluation-Requirements Gaps

[109] Raytheon, *Enhanced Position Location Reporting System-Extended Frequency.* White Paper, Fullerton, CA: Raytheon Company, 2009.

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# VIII. CONCLUSIONS

## A. ASSESSMENT

Applying the information systems model described in Chapter II, to the evaluation of current and emerging network technologies can provide a discriminating and useful perspective on the determination of the overall value for which a system provides. The majority of the current systems are obviously intended primarily for voice communication. This makes sense in that operations at the lower tactical levels have traditionally been conducted via voice communications; and should be in the future. However, if we are honestly attempting to move towards a truly NCW doctrine, then it is incumbent upon those of us in the DoD's information technology arena to re-examine the design and doctrine that enables operations at this lower tactical level. This is particularly true in the concept of ECO.

A small percentage of the systems evaluated in Chapter VII achieve some degree of network switching/routing capability, but the majority of the systems simply do not possess a true Layer-3 capability. According to the BIRM, this prevents a system from being interoperable at the first layer, and therefore should be the first level of evaluation when comparing information systems to the characteristics of the BIRM. From the outset, this prevents multiple networks, which may possess an operational imperative, from becoming an internetwork. The de facto value of "n," or combat power, among these systems is lower as a result of their non-interoperability.

The same devaluation of "n" is true for those systems that are not mesh capable. That is, they do not have the capability to directly connect to each other. Or, they do not dynamically update and optimize those connections. These systems are characteristic of legacy networks that only achieve the value of "n" in a linear fashion, similar to a broadcast-only network.

None of the current and emerging systems are converging voice and data, and are therefore wasting precious bandwidth in a wireless system. Granted, these systems must be able to communicate with legacy systems, but the transition must take place at some point. This transition is possible now with the use of gateways. This is done by isolating legacy voice systems behind a gateway which uses a software application to convert digital voice to VoIP.[110] It is clearly evident that, by dividing up channel spaces between IP-based data and digital voice, bandwidth is not being optimized. Additionally, the network devices are forced to deal with these two disparate media. So instead of carrying around a dedicated network device that is efficiently processing a single form of information, the Marine must carry around the functionality of several different devices crammed into one unit. Given limited space, power, and weight of any device, would it not be more efficient and capable if the device were focused on a single format of data?

Those systems that are not truly extending the GIG to the individual Marine are only creating more network complexity by generating the requirement for an additional gateway to reach the Convergence Layer. The ultimate goal, for which the above observations support, is to extend the Convergence Layer of the GIG to the individual Marine. Only then will we achieve NCW at the lowest tactical level, thus generating increased combat power and the exponential advantages of ECO.

## B. OPTIMAL COMMUNICATION SOLUTION

The optimal communication solution for enabling ECO is one that is designed to ensure interoperability. Current and emerging information systems are inadequate for the purpose of harnessing the exponential rate of increasing

[110] Clayton A. Craig and Christopher S. Tsirlis, "Command & Control for Distributed Operations: An Analysis of Possible Technologies, Structure & Employment." *Thesis.* Naval Postgraduate School, June 2007.

value achieved by a truly interoperable tactical mesh network. These systems do not provide a scalable architecture that will exploit the concept of network-centric warfare.

None of the radios/network devices surveyed in Chapter VII meet the critical requirements of modularity, which allows us to achieve interoperability. Modularity allows us to achieve three primary advantageous: interoperability, maintainability, and “futureproofing.” “Futureproofing” being the characteristic that allows us to set our tactical networks up for unknown future requirements. Much like the common networking standards we use today, such as Ethernet and Internet Protocol, have ensured the modularization and profligate evolution of the internet, a modularized tactical network architecture will enable the interchanging and adaptation of better and better transmission systems and endpoint devices.

ECO and those CAPSET V users share the same fundamental requirement: the extension of the GIG to the individual Marine. Based on the capability requirements identified in the MCWL’s ECO Concept, and those identified in MCCDC’s CAPSET V study, it is determined that, while the operational doctrine may be slightly different, both concepts require the same overall information system requirements. The network, and the endpoint devices that process data on the network, must be encapsulated in an overall architectural design that not only supports interoperability but establishes a foundation for future innovation and development in both the component’s design and use of the information system.

By laying the foundation for interoperability, we are ensuring that small tactical mesh networks can be internetworked among themselves and with subordinate, adjacent, and higher units seamlessly. In essence, we are ensuring that all Marine units can exploit the known and unknown advantages of an NCW capability. In doing so, we will be in a position to leverage the concept of ECO in the conduct of future Marine Corps combat operations.

## C. RECOMMENDATIONS

Any future decisions on information systems requirements in the Marine Corps must focus on the architecture. Instead of focusing on specific functional requirements aligned with operational C2 capabilities, future analyses must focus on modular design. It is imperative that current and future network communication systems be evaluated based on their modularity and thus their capacity for interoperability. While this thesis focuses on communication solutions for smaller tactical units, the requirements identified here can apply to communication solutions in all capability sets.

The acquisition of future network communication solutions must adhere to the concepts of Layer-3 capability and the extension of the GIG's convergence layer to the individual Marine. By decoupling endpoint device functionality from the communications network, a degree of modularity will enable an infinite degree of usability and interchange. Future acquisitions of wireless communication systems should ensure scalability with the demand of a stable MAC. They should ensure efficient use of the very limited resource of wireless bandwidth with multicasting and fault control/monitoring capabilities. Infinite possibilities exist for tactical network users, as they will not just be tied into the GIG, but they will already be on the GIG's convergence layer, and their reach will be global.

Modularity must also be considered in the acquisition of endpoint devices. By following the "Good Network Citizens" criteria, future endpoint devices can be purchased in a rapid acquisition cycle and maintain the capability to be interchanged and reused with multiple communication solutions. For example, the image and video capturing sniper scope, or target designation device will have the same network capabilities whether used with a small unit conducting ECO or employed on a UAV, because they would have the necessary network components to ensure interoperability.

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